The BROWN & SHARPE HANDBOOK



A GUIDE for YOUNG MACHINISTS

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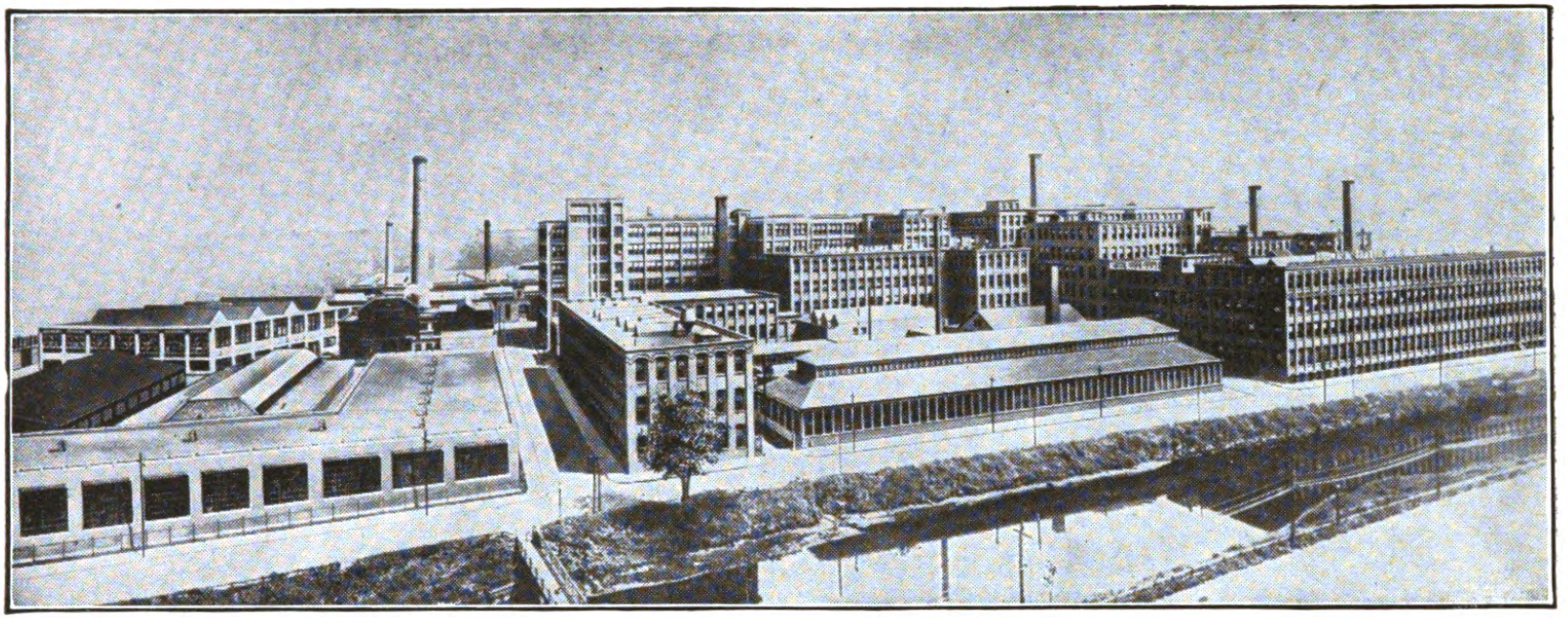
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THE BROWN & SHARPE MFG. CO.

The business conducted by the Brown & Sharpe Mfg. Co. was founded in 1833 by David Brown and his son, Joseph R. Brown. This business, which had its beginning in a small watch and clock shop, now requires the facilities of the huge plant shown above, the largest of its kind in the world. The fourteen main manufacturing buildings, the foundry, forging, hardening, central power plant and other miscellaneous buildings include over 1,463,000 square feet, or over 33 acres of floor space.

The works are located but a short distance from the business center of Providence and visitors always are welcome. All kinds of machinists' tools, cutters and machine tools may be seen at the plant in the course of construction or actually in use under manufacturing conditions.

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The Brown & Sharpe Handbook

A Guide for Young Machinists



Brown & Sharpe Mfg. Co.
Providence, R. I., U. S. A.
1947

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PREFACE

This book is intended to be a helpful guide and useful reference manual for the beginner. The numerous illustrations and diagrams should prove unusually helpful in comprehending the text. The many tables throughout the book should be of value even after the text becomes familiar.

Needless to say, this book is not intended to take the place of engineers' handbooks nor does it attempt to cover the field in such detail as the excellent textbooks recommended for apprentices to read. But, if it succeeds in clearing up some of the problems that baffle the young apprentice and inspires him with some of the old-time spirit of the master craftsman, it will have accomplished its purpose.

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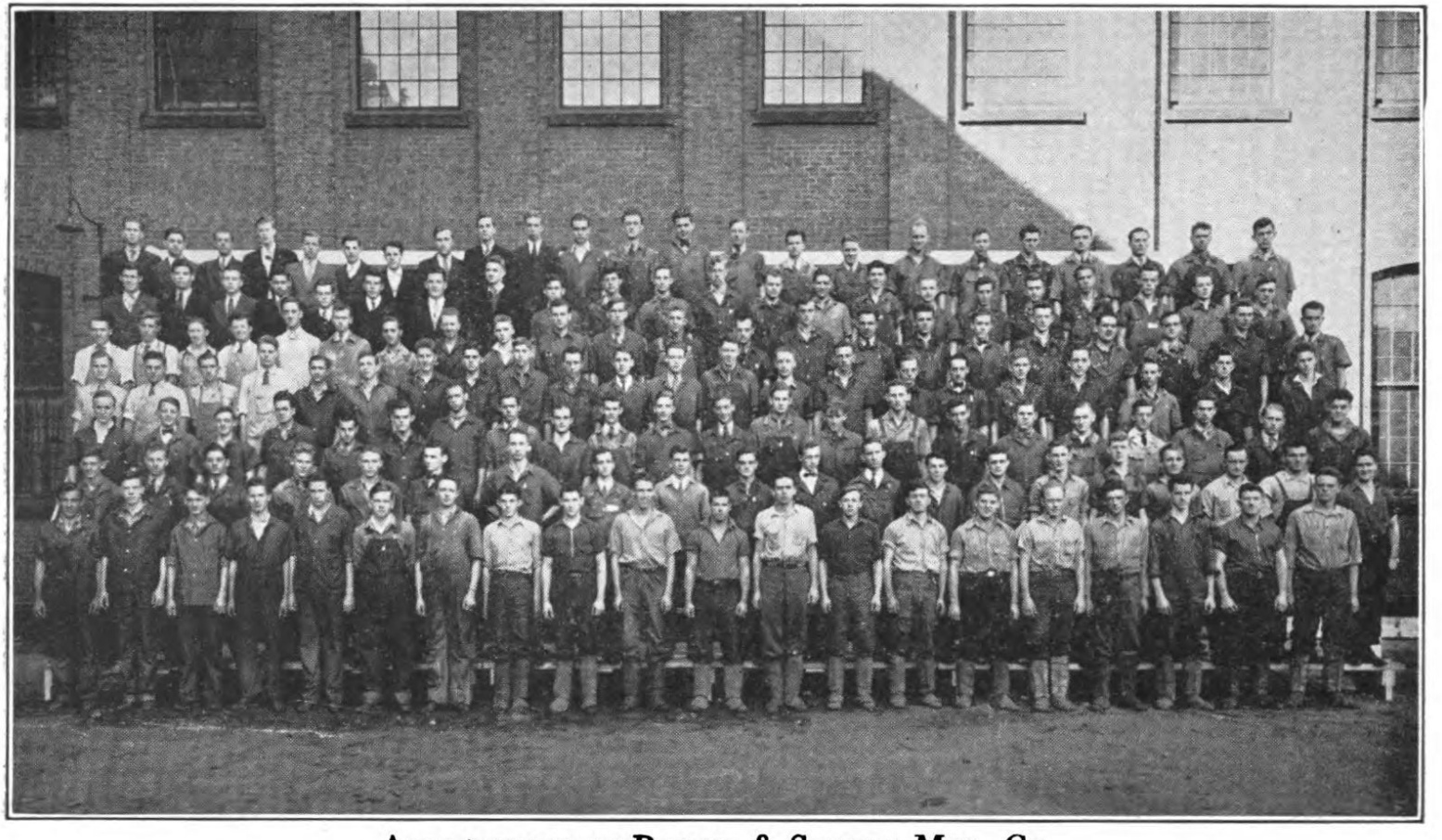
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Apprentices at Brown & Sharpe Mfg. Co.

These young men, from all parts of the country, are training to become skilled machinists, molders, core makers, pattern makers, draftsmen or screw machine operators. See page 310.

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A WORD TO THE YOUNG MACHINIST

In learning the machinist's trade nothing can take the place of actual shop work to help a young machinist become familiar with the multitude of facts and methods which constitute a thorough mechanical knowledge. However, there are numerous facts and methods that can be readily acquired by reading and study.

With the exception of a few shops that have a well organized apprenticeship course, many do not seem to have the time or facilities to furnish the beginner with all of the practical experience he may require. In addition, shops are becoming more specialized and it is increasingly difficult for a young man to get the diversified training that he needs.

For this reason the young machinist should acquire the habit of study and of reading along the lines of his trade. He should, at the beginning of his course, acquire some current books on machine shop practice and keep in touch with new ideas in his specialized field by reading mechanical magazines.

On pages 307 and 308 are listed several useful books and periodicals on machine shop practice. An apprentice should avail himself of their valuable assistance either by buying them or by obtaining them from a public library. It is surprising how much practical knowledge can be gained from a good textbook in an evening's quiet of one's room.

Learning a trade is a serious affair and in his work the apprentice should make it a point to understand thoroughly each step as he goes along. Do not hesitate to ask questions; it is a quick way to settle a doubt.

Care of Self. — Carelessness is the great menace in a machine shop. It must come from the man himself for certainly the machines alone cannot inflict injury. Lack of care causes most of the accidents in machine shops today.

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At the very beginning it should be remembered that it is dangerous to lean against a machine that is in operation; in fact, keep clear of any mechanism that is in mesh or motion, or that is likely to be set in motion by someone else. If it is necessary to place the hand on a moving piece, know beforehand the direction of its motion. Be particularly careful when working around gears and cutters.

In shifting a belt that is running, use a stick or the handle of a hammer or a wrench. Do not use the hand if this can be avoided as there is always danger of getting cut with a belt hook or burned by friction. If necessary to shift a belt by hand, the hand should be kept straight, and should touch the belt upon its edge only. If the fingers are bent they may get caught between the belt and the pulley. Never play with the adjustments of a machine or idly turn the handle. Do not set a lathe tool or a planer tool while the work is in motion. Bear in mind that a machine may inflict severe punishment for a careless movement. Treat a machine with businesslike respect and there is no need of fearing it. Do not start a machine until its operation has been fully explained by a competent instructor.

Never oil overhead works while the shaft is in motion.

Make sure that overalls are in good condition with the jumper tucked inside of the trousers with no loose or torn ends to catch in revolving parts. Never wear a loosely hanging necktie. Never use gloves. Keep both sleeves above the elbows.

Never clean, adjust or repair a machine while it is in operation.

Never clean running gears.

After fastening the work in the chuck, give the chuck a complete turn to make sure that the work clears the machine. Be sure to remove the wrench from the chuck before starting the machine.

Never use the hand to hold a piece of work on a drilling machine; use a clamp or a vise.

Never brush chips away with the hand; always use a suitable brush.

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Never run a grinding wheel faster than the speed which is recommended.

Be sure to use the guard over a grinding wheel. If it is necessary to work with the guard off the wheel, stand to one side in order to avoid flying particles of emery and the possibility of serious injury in case the wheel should break.

While using a rest to grind tools be sure that the rest is close to the grinding wheel.

Be sure to use goggles or a glass shield, if the machine is so equipped, when grinding with a dry wheel.

Just before starting a planer, note the position of all the fixtures, clamps and dogs on the table to make sure that everything is clear when the table is set in operation.

Keep bolts, nuts and tools off the planer table as they are likely to fall into the gearing in the bed.

Do not use the space in the bed of a planer as a storage place for tools: serious accidents have happened when a workman has tried to take them from such a place while the table has been in motion. This space should be covered with a guard.

Never use a file without a handle.

Never chip toward a person; use a screen if necessary.

Keep the heads of chisels free from burrs.

While pouring babbitt, use goggles.

Keep all moisture away from hot babbitt, solder, and lead to avoid a serious explosion.

Report promptly to the first aid supervisor any cut or bruise.

Care of a Machine. — Do not allow a tool to run by the work so far as to score the chuck or lathe spindle. Be careful not to score the platen of a planer. Do not let a lathe tool score a mandrel. Do not drill holes carelessly in the table of a drill press. Do not let the cutter gouge the footstock or vise of a milling machine. Do not lay a file or any other tool on the ways of a machine or on any other scraped or aligned surface. Protect the ways as much as possible.

The running parts of a machine should be oiled daily, and

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sometimes more often. Slides and other exposed bearings should be wiped clean before oiling, and, when starting work on a machine that someone else has been operating, do not assume that it has been oiled; oil it yourself. Be sure the oilways are not plugged with dirt. It is a bad sign when oil remains in the holes without sinking, particularly when the part is in motion. If the oil hole is plugged it is safer to take the bearing apart and clean the oilways. Sometimes an oil hole can be cleaned by forcing in gasoline.

Personal neatness together with a clean and orderly machine is an indication of a good workman.

Spoiled Work. — Do not hesitate to report spoiled work promptly. It will cost much more to make up the deficiency when the job is turned in. Do not be afraid to admit an error. Honesty of this kind quickly wins the respect of any supervisor.

Tools and Work. — While in use, tools should be arranged so that they can be easily reached. Do not throw files together; this is a practice that will soon destroy their usefulness. It is poor workmanship to use a monkey wrench for a hammer. Jamming a piece of finished work in the jaws of a vise or under a set screw indicates that the workman is rough and careless in his methods. See that the vise is supplied with copper jaws for the jobs which require them.

Rust. — Watch out for rust. It is a bitter enemy of steel and without the protection of grease and oil, steel usually gets the worst of it. Be sure that a surface is clean before applying a protective coating. Perspiration is very corrosive, so be careful after using the finer tools like micrometer calipers, gages and verniers to wipe them clean and cover with a thin coat of oil before putting them away.

Attention to Instructions and Drawings. — Be sure your instructions are understood. Do not attempt to start work with the foreman's instructions only partly understood. When starting work on a piece of stock be sure to examine it for flaws and blow holes and measure it to see whether it will finish

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to the required dimensions. This precaution will prevent the possibility of wasting time on a piece that may eventually be thrown into the scrap. If an operation is to be performed on a piece that has been worked on by someone else, be sure to check up their work before starting on the piece; by so doing there will be no question as to who is responsible in case of error. When a job is almost done do not be too sure that it is coming out right; be as careful at the finish as at the start. Know the peculiarities of the job and as it progresses exercise care by checking up the work, and thus avoid careless errors.

At the beginning it will be well for a young machinist to do his work as carefully and accurately as he is able; then, after he becomes confident that he can do good work, he can give his attention to production. He should discriminate between parts that must be finished to small limits and parts that need to be machined only to make them smooth — not waste time in accurately machining to size, parts that do not require it.

Certain men develop the habit of always doing their work as though every part required extreme accuracy. On the other hand, others may finish certain parts close enough for all practical purposes and turn out a much greater volume of work. Furthermore, some men are so efficient that they are capable of doing both fine and rough work with equal facility; men of this type are in demand.

Cultivate the ability to change from one job to another. If there are several pieces in a job, make plans for the successive operations while the present pieces are being machined.

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CHAPTER I

Drawings

The mechanical drawing is the means by which the draftsman gives instructions as to how a piece of work is to be made.

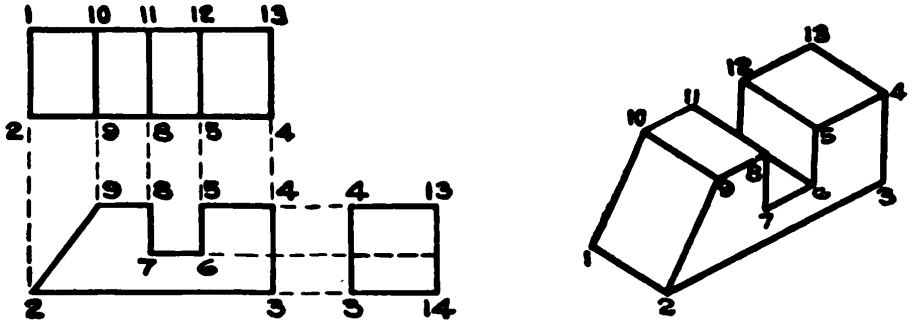


Fig. 1. Two methods of representing the same piece. Numbers indicate respective points on each drawing. Left: a simple third angle projection. When dimension figures are given it is a Working Drawing. Right: Isometric Drawing

Working Drawing. — The usual method is the working drawing, showing as many views of the piece as may be necessary and indicating its shape, size, dimensions and material.

Isometric Drawing. — Occasionally an isometric drawing is used to convey ideas as to the shape and dimensions of a piece. This kind of drawing sometimes proves valuable for the instruction of a person who does not understand working drawings. It is seldom used by draftsmen, but it is true, nevertheless, that a rough isometric drawing may convey an idea to a person when a working drawing proves too complicated. In an isometric drawing the object is represented in such a manner that all the lines on the drawing are made proportional to the respective lines on the object. The lines that represent length and breadth make angles of 30° with the horizontal and the lines of thickness are vertical.

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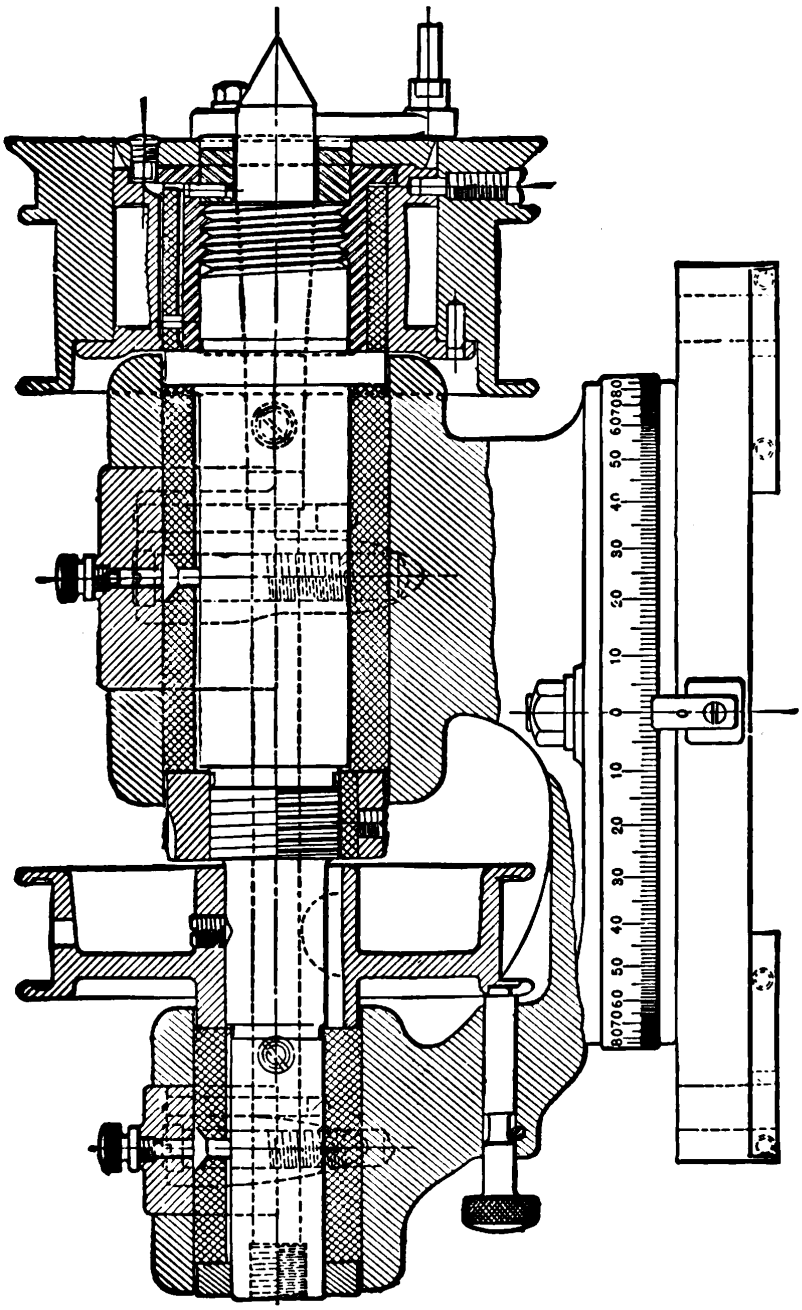


Fig. 2. An Assembly Drawing—it shows the position of the parts when they are all in place. Any dimensions that may be given are for purposes of assembling and erecting only

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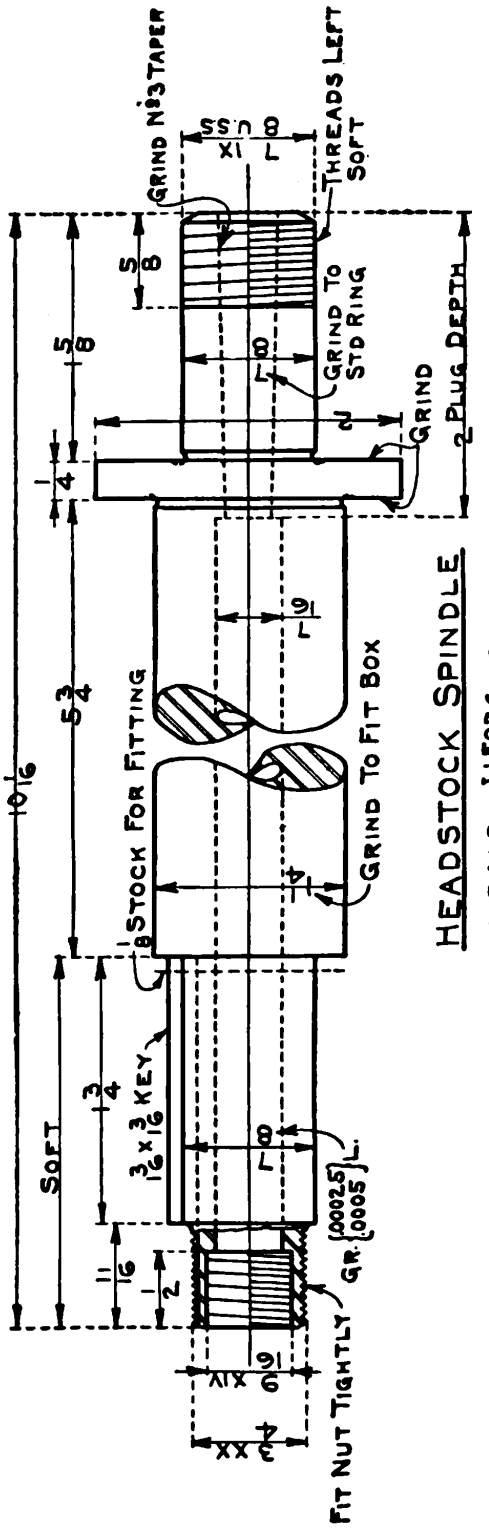


Fig. 3. A Detail Working Drawing — it shows the part by itself and includes dimensions, name of the material, number of pieces and any other information that may be required to make the piece

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Full Line, thus, ———————— represents the visible edges of the object.

Dotted Line, thus, - - - - - - - - represents the invisible edges of the object.

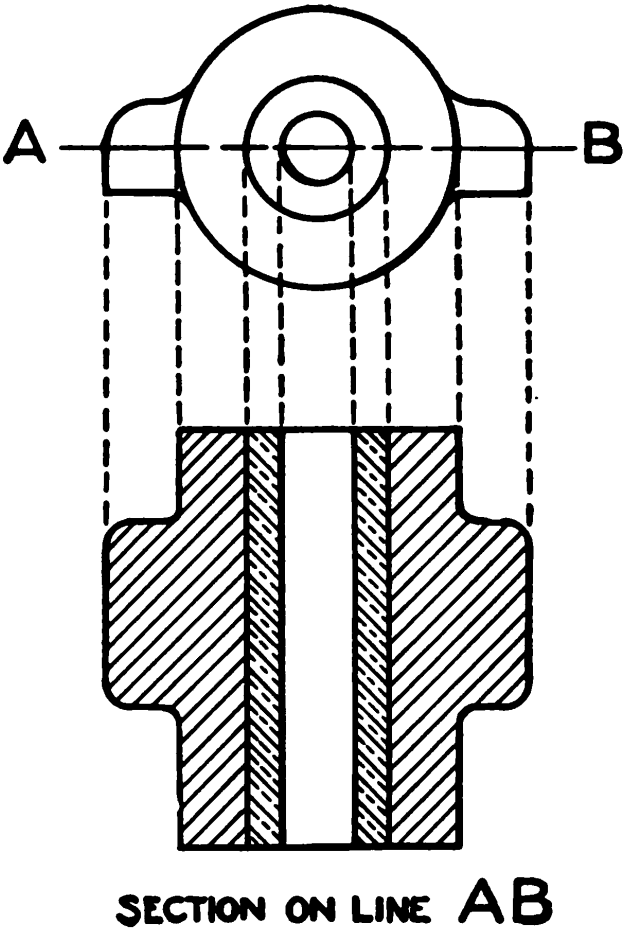


Fig. 4. A Section Drawing — it shows a part of the assembly in such a way as to give the appearance that the stock has been cut away to reveal the internal construction. The position of a section is indicated by a center line marked with two letters. The section view is marked the same

Fine or Broken Line, thus, ———————— or ———·———·——— may represent a center line from which all layouts should start. (*Note*: It is still the practice in many drafting rooms to use a broken line, thus, ——-———-——— for a center line, but in shops

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where drafting as well as machine work has been subjected to a vigorous simplifying process, many of the earlier practices, like shading and fancy lettering have been discontinued in the interest of economy, time and greater production.)

Dimension Line, thus, ←——— 5″ ———→ is ordinarily a fine line with a break at a convenient point for dimension figures. (*Note*: Sometimes the break in the dimension line is omitted and the dimension is put on the line as in Fig. 3.) An arrowhead appears at each end and dimension figures are placed in the break of the line so as to read from the bottom of the drawing or from its right-hand edge.

Section Lining or Cross Hatching in a mechanical drawing is an arrangement of lines drawn parallel and equidistant usually at an angle of 45° to represent materials of construction, surfaces that are cut, and to distinguish between parts that are adjacent.

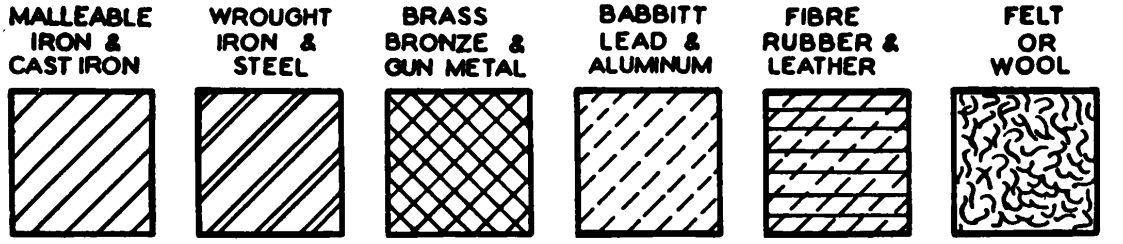


Fig. 5. Section Lining representing Materials of Construction

When two pieces of the same material are in contact, it is necessary to change the direction of the section lining and in some cases to use lines at a different angle in order to indicate the division as shown in Fig. 2.

Extension or Witness Lines are used to connect a dimension line with its subject.

Dimensions should be indicated with great care. Figures relating to the shorter dimensions of the piece should be in lines drawn close to the piece. Over-all dimensions should appear outside of the shorter dimension lines. Dimensions are commonly represented in inches up to and including 144 inches; dimensions higher than 144″, should be represented in feet and

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inches, thus, 12′ 6″. As mentioned before, the dimension figures should run parallel with either the bottom or right-hand edge of the drawing.

To save space drawings often show a section omitted as indicated in the center of Fig. 3. Sometimes these breaks are section lined illustrating kinds of material.

The respective views of blueprints are read from left to right and fractional sizes are understood to be ± .010″, decimal figures to be exact and holes to be standard unless otherwise specified.

A FEW ABBREVIATIONS USED ON DRAWINGS

Abb.	*Meaning*	*Abb.*	*Meaning*
′	Feet or minutes	C.M.S.	Crucible machinery steel
″	Inches or seconds	S.M.S.	Soft machinery steel
°	Degrees	M.I.	Malleable iron
mm	Millimeter	W.I.	Wrought iron
M.	Meter	B.BZ.	Bearing bronze
Dia. or Diam.	Diameter	G.M.	Gun metal
R.H.	Right-Hand	P.BZ.	Phosphor bronze
L.H.	Left-Hand	B.	Brass
P	Diametral Pitch	S.C.	Steel castings
P′	Circular (axial) Pitch	S.S.C.	Semi-steel castings
T	Teeth	SH.I.	Sheet iron
Rad.	Radius	C.I.	Cast iron
Gr.	Grind	M.S.	Machinery steel
N.C.	National Coarse	C.S.	Carbon steel
N.F.	National Fine	C.R.S.	Cold rolled steel
H.S.S.	High speed steel	T.S.	Tool steel
C.H.	Caseharden		

Bolt and Screw Lists are a tabulation of the various bolts, nuts and screws, together with their symbol numbers and the number of each required to complete the machine.

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Limit System. — The limit indicates to the operator or mechanic the degree of accuracy required in the work. It states specifically the amount of tolerance or variation in measurement, either over or under, which is allowable for the work to pass inspection. It recognizes the truth that an unnecessarily high degree of accuracy is not economical and that for parts to be interchangeable a margin of variation from absolute accuracy must be allowed.

A limit is the dimension which the work must not exceed. For instance, if the diameter of a hole in a piece of work is to be 1″ and the oversize limit is 1.001″ and the undersize limit is .999″ then any work not over 1.001″ nor under .999″ will be accepted. The limit may be said to be plus or minus .001″. The words plus or minus are expressed thus, ±.

Tolerance is the difference between the maximum and minimum limits; that is, with a maximum limit of 1.001″ and a minimum limit of .999″ the tolerance would be .002″. The tolerance may be divided into plus or minus depending upon whether it is above or below the normal size.

Allowance applies particularly to fits, as in the case of a hole and a shaft. It is the difference allowed in the two diameters in order to accomplish the desired fit. There are forcing, driving, running and sliding fits. The table on page 283 shows the various allowances that correspond to these fits.

Systems of Measurement. — There are two systems of linear measurements with which the apprentice should become familiar. The English System, which is in general use in most English speaking countries, is based on the yard and is expressed in inches and feet. The Metric System is in use in European and most foreign countries, and in the United States in the manufacture of certain scientific apparatus and, in some cases, on machinery for export to countries where the Metric System is standard. Measurements in the Metric System are expressed in parts of a meter.

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In accordance with the standard practice approved by the American Standards Association, the ratio 25.4 mm = 1 inch is used for converting millimeters to inches. This factor varies only two millionths of an inch from the more exact factor 25.40005 mm, a difference so small as to be negligible for industrial length measurements.

METRIC MEASURES

The metric unit of length is the meter = 39.37 inches.

The metric unit of weight is the gram = 15.432 grains.

The following prefixes are used for sub-divisions and multiples: Milli = $\frac{1}{1000}$, Centi = $\frac{1}{100}$, Deci = $\frac{1}{10}$, Deca = 10, Hecto = 100, Kilo = 1000, Myria = 10,000.

METRIC AND ENGLISH EQUIVALENT MEASURES

Measures of Length

Metric	*English*
1 meter	= 39.37 inches, or 3.28083 feet, 1.09361 yards
.3048 meter	= 1 foot
1 centimeter	= .3937 inch
2.54 centimeters	= 1 inch
1 millimeter	= .03937 inch, or nearly 1-25 inch
25.4 millimeters	= 1 inch
1 kilometer	= 1093.61 yards, or 0.62137 mile

Measures of Weight

Metric		*English*
1 gram	=	15.432 grains
.0648 gram	=	1 grain
28.35 grams	=	1 ounce avoirdupois
1 kilogram	=	2.2046 pounds
.4536 kilogram	=	1 pound
1 metric ton 1000 kilograms	=	.9842 ton of 2240 pounds 19.68 cwt. 2204.6 pounds
1.016 metric tons 1016 kilograms	=	1 ton of 2240 pounds

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Measures of Capacity

Metric		*English*
1 liter (= 1 cubic decimeter)	=	61.023 cubic inches .03531 cubic foot .2642 gal. (American) 2.202 lb. of water at 62° F.
28.317 liters	=	1 cubic foot
4.543 liters	=	1 gallon (Imperial)
3.785 liters	=	1 gallon (American)

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CHAPTER II

The Use of Layout and Inspection Tools

The apprentice, as well as the experienced machinist, should consider a good set of tools a wise investment. Tools of standard quality will last a lifetime, barring accidents, abuse and loss by being " borrowed." In selecting tools, the best are none too good, for good tools give confidence, and confidence helps to improve the quality of work.

With the increasing use of jigs and fixtures, layout work has diminished to a certain extent, but of course to originate the jigs and fixtures it will continue to be practiced, and with a high degree of accuracy.

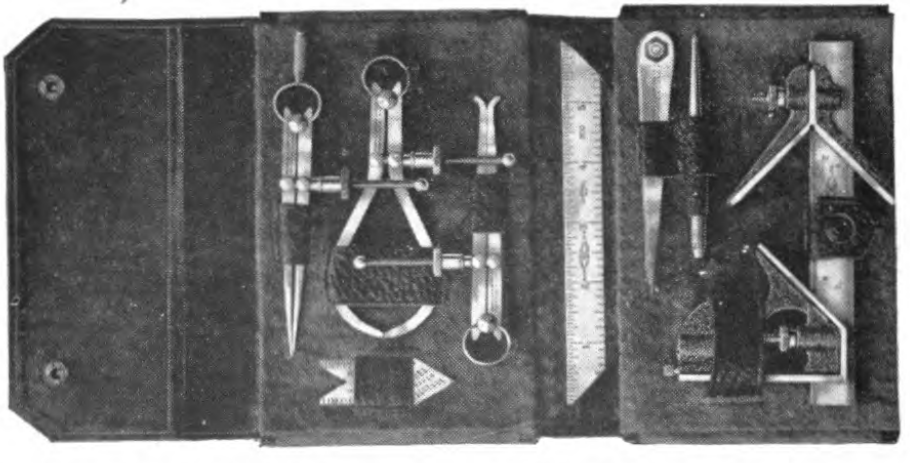
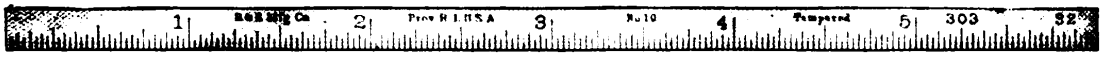


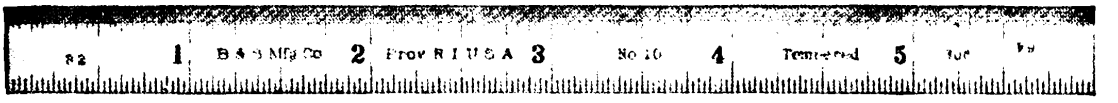
Fig. 6. Set of Apprentice Tools in a folding leatherette case

Rules and Their Uses. — In addition to the familiar boxwood two-foot rule, there is a multitude of different kinds of rules and scales. Each kind is especially adapted to certain classes of work, and, by choosing the proper rule it is easier for the mechanic to obtain accurate measurements. It is necessary to know about these different kinds of rules even though it may not be necessary to use them all.

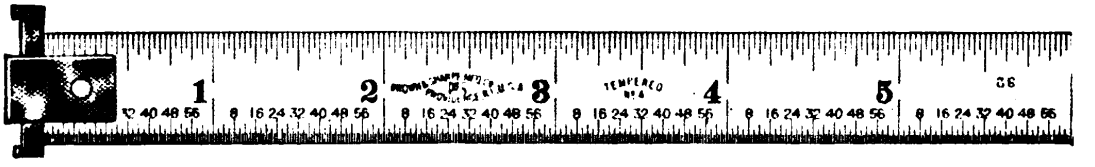
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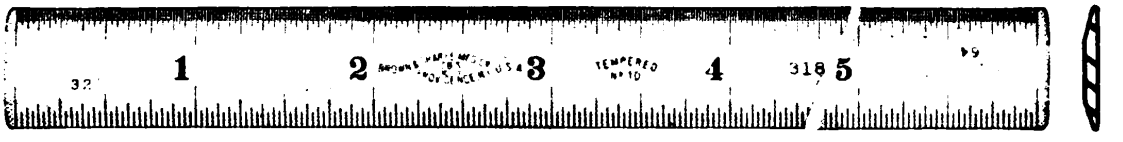
Narrow Rule



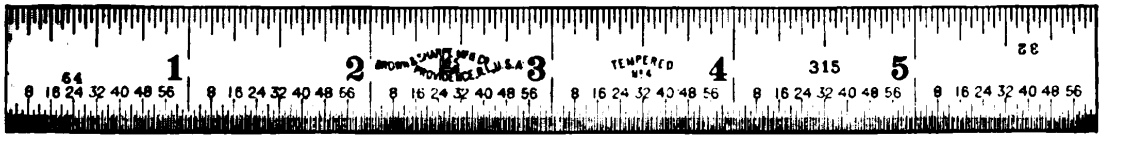
Flexible Rule



Hook Rule



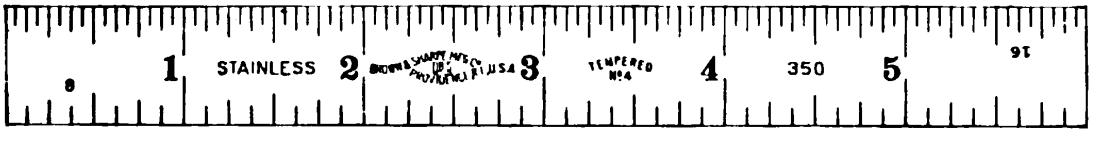
Beveled Edge Rule



Rule with Figured Graduations



Keyseat Rule



Common type of Rule

Fig. 7. Various kinds of Tempered Steel Rules

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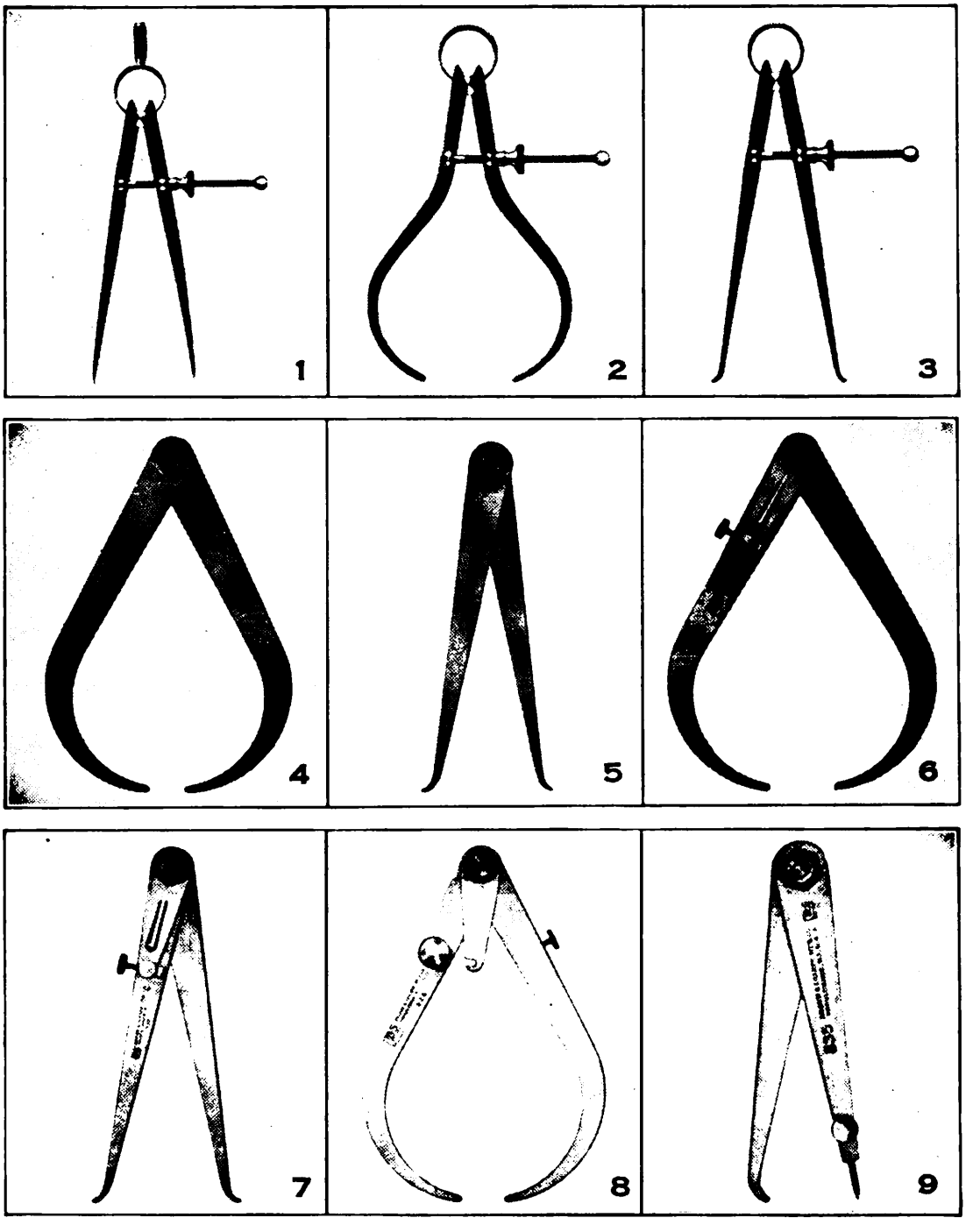


Fig. 8. Types of Dividers and Calipers

1. Spring Divider
2. Outside Spring Caliper
3. Inside Spring Caliper
4. Firm-Joint Outside Caliper
5. Firm-Joint Inside Caliper
6. Screw Adjusting Firm-Joint Outside Caliper
7. Screw Adjusting Firm-Joint Inside Caliper
8. Transfer Firm-Joint Outside Caliper
9. Firm-Joint Hermaphrodite Caliper

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Calipers and Their Use. — In making contact measurements where extreme accuracy is not required, the spring caliper is commonly used. There are two general types, the outside caliper for outside measurements and the inside caliper for inside measurements.

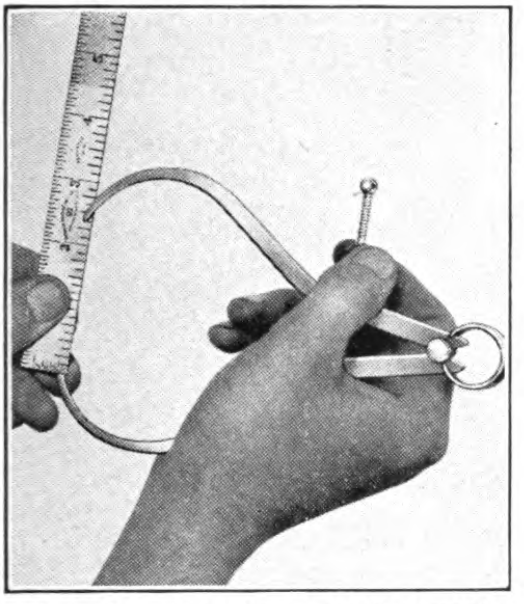


Fig. 9. Setting an Outside Caliper

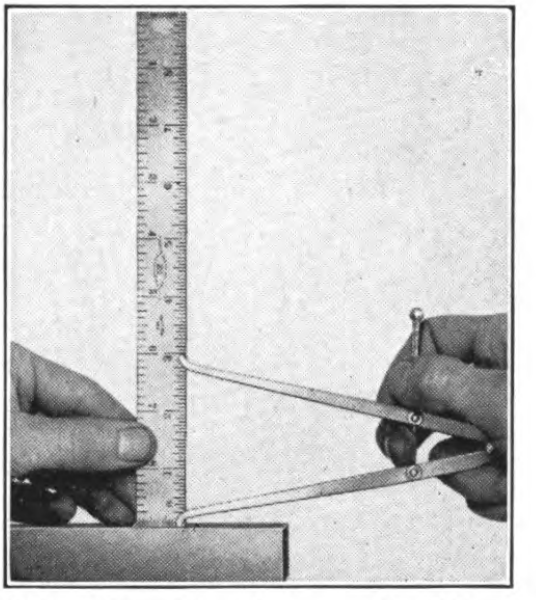


Fig. 10. Setting an Inside Caliper

Ordinarily the spring caliper is set by means of a steel rule. By using a reading glass and exercising due care, a caliper can be set so that measurements can be taken fairly accurately. For work requiring greater accuracy, fixed gages, like plug or ring gages, must be used in setting the caliper. When the caliper, whether inside or outside, is to be set by a steel rule it is customary to use methods similar to those shown in Figs. 9 and 10. The outside caliper should be held so as to keep both points of the legs an equal distance from the edge of the rule. The inside caliper should be set by placing one leg against a flat surface perpendicular to the edge of the rule, as shown in Fig. 10. (*Note*: In setting to the graduations be sure to set to the center of the graduation line.) Inside calipers can also be set very accurately between the contact points of an outside micrometer caliper.

Some persons have a sense of touch more highly developed

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than others. The degree to which their sense of "feel" is developed has a great effect on the accuracy of their work

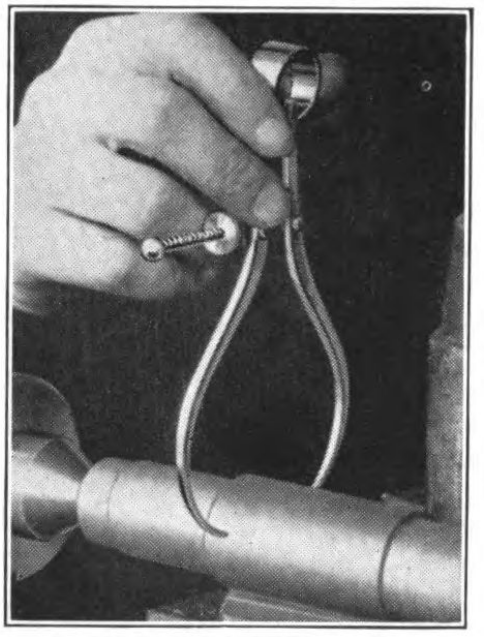


Fig. 11. Outside Spring Caliper in use

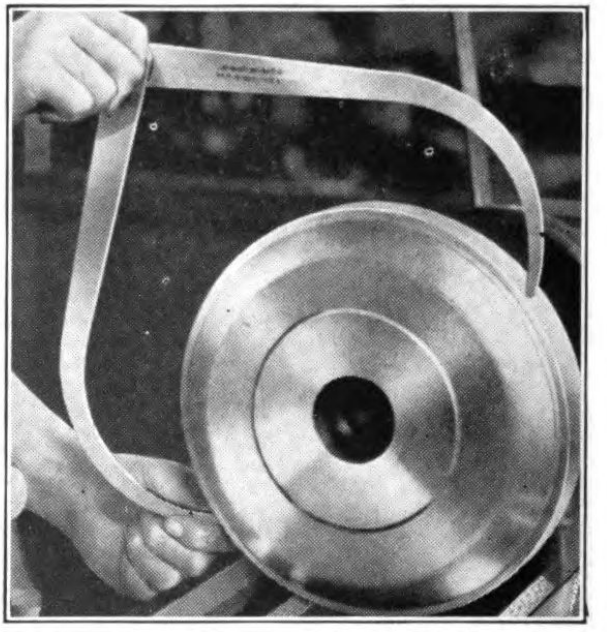


Fig. 12. Firm-Joint Caliper in use

with the caliper. Use only the tips of the fingers in holding a caliper; never grip it too firmly. Relax the fingers to increase their sensitiveness to feel. A skilled mechanic can often detect a difference in diameter as small as a thousandth of an inch.

Calipers made without a spring are known as firm-joint calipers; Fig. 12 shows this type in use. In setting them, they may be brought to the approximate measurement by hand, and then by gently tapping them, they may be opened or closed to the desired dimension.

Some firm-joint calipers have an adjusting screw that makes it possible to obtain a fine adjustment, and dispenses with the necessity for tapping the legs on an object.

The Micrometer Caliper. — At the Paris Exposition in 1867, Messrs. J. R. Brown and Lucian Sharpe saw displayed "Système Palmer," a measuring tool patented in France in 1848. Impressed with the possibilities of this tool, they introduced upon their return to America, the Pocket Sheet Metal Gage,

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the first practical micrometer caliper, reading in thousandths of an inch.

From this beginning, the Brown & Sharpe line of Micrometer Calipers has been developed through ideas worked out in its own shop, and by acquired patents, to include over four hundred different micrometer calipers which meet the demands of all ordinary shop requirements.

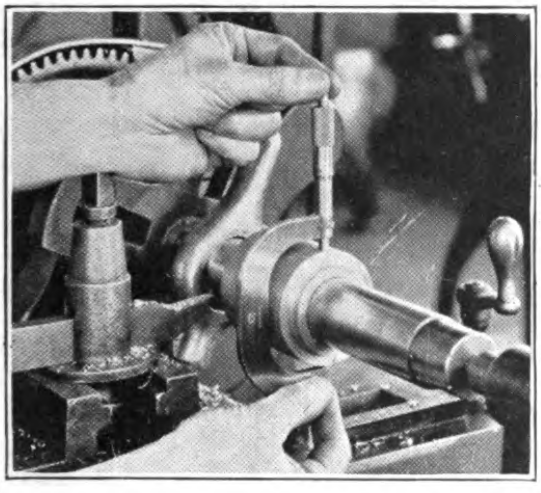


Fig. 13. Measuring lathe work with a Micrometer Caliper

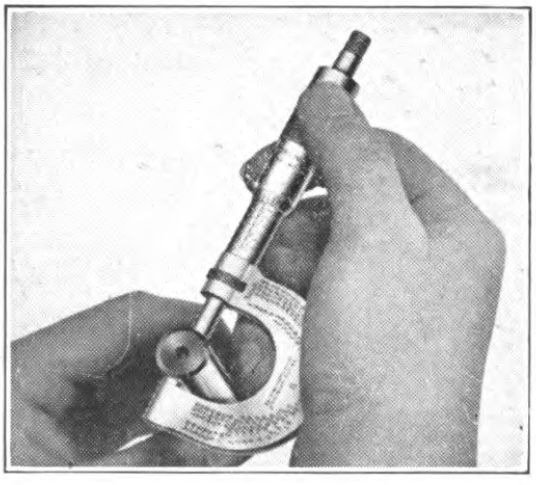


Fig. 14. Proper way to hold a Micrometer Caliper when sizing small work

Recent developments and improvements in micrometer calipers include the use of rust and wear resisting alloys for the anvils and spindles; the use of stainless steel for frames, barrels and thimbles; a hardened measuring screw with ground threads for enduring accuracy; the tipping of the measuring surfaces of anvils and spindles with tungsten carbide, an almost wear-proof alloy for use in measuring over abrasives and cutting edges; and a patented device which permits the micrometer to read ten-thousandths of an inch direct and parts of ten-thousandths of an inch to be estimated. The apprentice should familiarize himself with these and other new developments to be better able to know the tools available which may be best suited for certain work.

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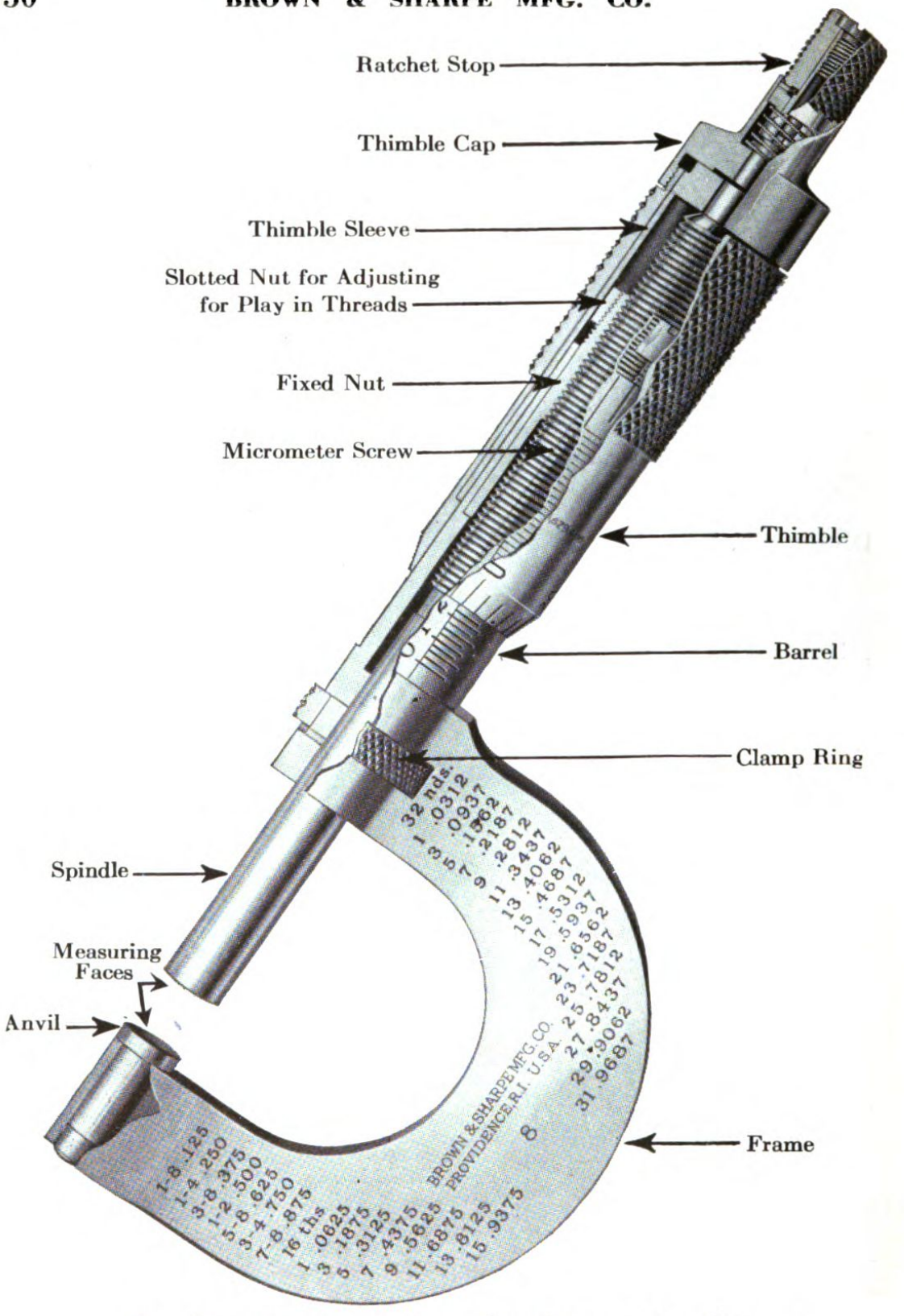


Fig. 15. Sectional view of a Micrometer Caliper

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The Principle of the Micrometer Caliper. — The basic principle of the micrometer caliper is a very accurate screw, Fig. 15, free to move in an accurately threaded fixed nut which provides a variable opening between one end of the micrometer screw or spindle and a fixed contact face or anvil in the frame. The graduated thimble rotates with the spindle and travels along a graduated barrel. The graduations conform to the pitch of the micrometer screw, hence, there is a graduation on the

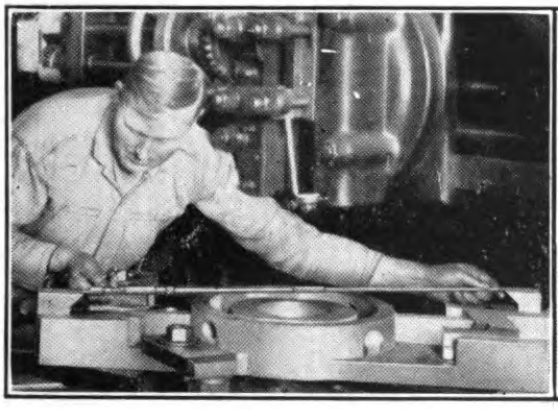


Fig. 16. Inside Micrometer for obtaining large measurements

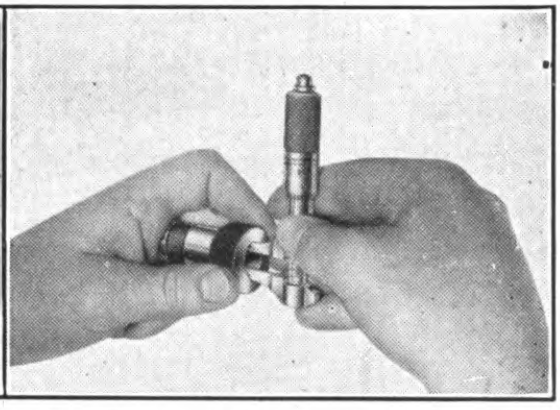


Fig. 17. Inside Micrometer Caliper for obtaining small inside measurements

barrel for each revolution of the micrometer screw. The graduations on the beveled edge of the thimble accurately divide each revolution of the screw so that measurements can be made in .001″ or .01 mm.

The Ratchet Stop furnished on some micrometer calipers provides the proper pressure at the measuring point against the work to be measured. Simply turn the knurled knob slowly the same number of "clicks" for each measurement. A couple of "clicks" gives the needed pressure.

The Clamp Ring is a convenience in keeping the micrometer at a particular setting. A slight rotation of the knurled ring locks the spindle.

Important. — Never tighten the clamp ring when the spindle is withdrawn. To do so injures the clamping mechanism.

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How to Read a Micrometer Graduated to Thousandths of an Inch. — The customary pitch of the screw in English measure micrometers is 1/40″ or .025″. This is equivalent to 40 threads per inch and means that, with one complete and exact revolution of the micrometer screw, the contact face at the end of the spindle has either moved away from or towards the face of the anvil exactly .025″. The beveled edge of the thimble is graduated into 25 parts each graduation representing 1/25 of .025″ (a complete revolution of the thimble), or .001″. Since the graduations on the barrel conform to the pitch of the micrometer screw, to make a measurement, count the number of these divisions visible and multiply by .025″ adding to the product the number of divisions on the thimble which have passed the long parallel or axial line on the barrel. Every fourth line on the barrel represents .100″ and is numbered 1, 2, 3, etc.

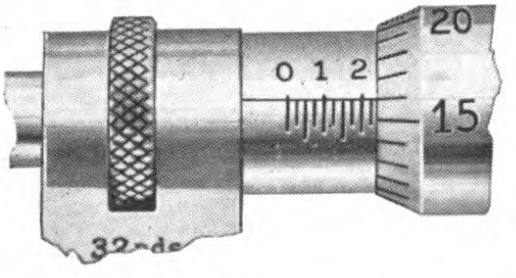


Fig. 18. English Graduations

Example. — Fig. 18

Highest figure visible on barrel . . . . . 2 = .200″

Lines visible between the number 2 and thimble edge . . . . . 1 = .025

Lines on thimble which have passed long line on barrel 16 = .016

Reading of measurement . . . . . Total = .241″

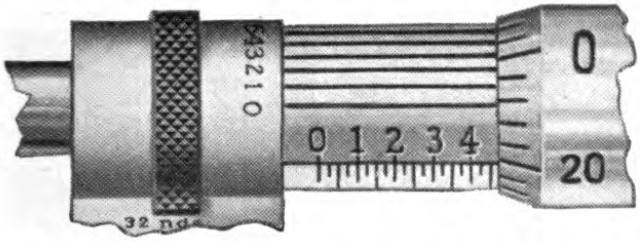
How to Read a Micrometer Graduated to One Ten-Thousandth of an Inch. — Readings in .0001″ are obtained by a Vernier on the barrel of the micrometer.

The Vernier has 10 divisions which equal the over-all space of 9 divisions on the thimble. Thus, one division on the Vernier = 1/10 x 9/1,000″ = 9/10,000″. Graduations on the thimble = 1/1,000″ or 10/10,000″. The difference between a division on the thimble and division on the barrel = 10/10,000″ − 9/10,000″ = 1/10,000″.

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The zero lines on the Vernier and the zero lines on the thimble coincide when the reading is exact in thousandths and the differences between the lines on thimble and lines on Vernier at 1, 2, 3, etc. = .0001″, .0002″, .0003″, etc. Thus, as the 1, 2, 3, etc., Vernier lines coincide with the thimble lines, the thimble has moved past the exact setting, 1, 2, 3, etc., ten-thousandths of an inch.

To Read. — First obtain reading in thousandths and add to this the ten-thousandths indicated by the coinciding lines of the Vernier and the thimble.



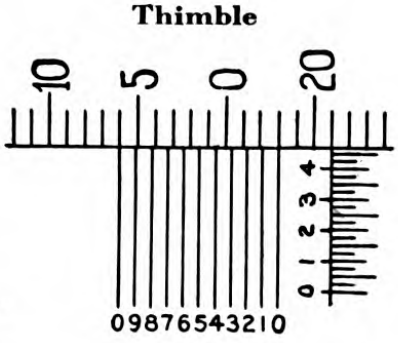


Fig. 19. Ten-Thousandths Graduations

Example. — Fig. 19. Upper Diagram

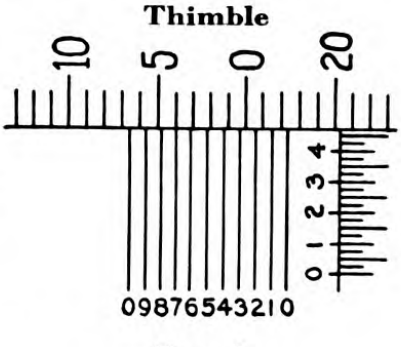
There are no ten-thousandths to add as the zero lines on Vernier coincide with lines on thimble.

Reading . . . . . = .4690″

Example. — Fig. 19. Lower Diagram

The 7th graduation on the Vernier coincides with the line on thimble indicating 7/10,000″ should be added to the thousandths reading.

Thousandths Reading . . .	.4690″
Ten-thousandths Reading indicated by Vernier . .	.0007
Reading . . . . . =	.4697″



How to Read a Micrometer Graduated to Millimeters. — The customary pitch of the screw is 1/2 mm. With one complete and exact revolution of the measuring screw, the contact

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face at the end of spindle either moves away from or towards the face of anvil exactly 1/2 mm or with two complete revolutions, a distance of 1.00 mm. The beveled edge of the thimble is graduated into 50 parts, each graduation representing 1/50 of a 1/2 mm (a complete revolution of thimble), or 1/100 mm. Since the graduations on the barrel conform to the pitch of the micrometer screw, to make a measurement, count the number of these divisions visible on the barrel. The upper set of graduations represent whole mm and the lower set divides each mm into two equal parts or 1/2 mm. Then add the hundredths of a mm shown by the line on the beveled edge of thimble that coincides with the horizontal line on the barrel.

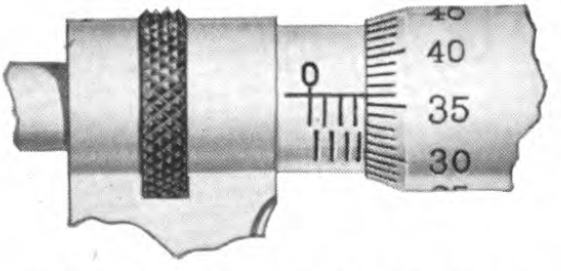


Fig. 20. Metric Graduations

Example. — Fig. 20

Whole mm lines visible on barrel	3 = 3.00 mm
Additional half mm line (lower) visible on barrel.	1 = .50
Lines on thimble which have passed long line on barrel.	36 = .36
Reading of measurement	Total = 3.86 mm

Lubrication. Remove spindle and clean threads with pure naphtha. When dry, place oil on threads with a toothpick. For micrometer calipers for outside measurements a high grade light lubricating oil should be used. For micrometers for inside measurements (except the type shown in Fig. 17 which requires a light oil) a high grade medium heavy lubricating oil is best. Take micrometer apart only when necessary.

The use of the micrometer determines how often it should be lubricated. In general use, lubrication should be required only infrequently.

Principle of the Vernier. — The Vernier was invented by Pierre Vernier in 1631. It consists of a small scale having a certain number of graduations, which equals, in combined length, a different number of graduations, usually one more or one less, on

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the long scale of the tool. It is evident that if, in the same extreme length, the Vernier has divisions greater or less in number by one than the scale, there is a small difference between a division on the Vernier and a division on the scale. The readings depend upon this difference between the Vernier and the scale divisions.

It was with this principle that Jos. R. Brown, so far as is known, invented in 1851 the first Vernier caliper.

Because the accuracy of a Vernier tool depends essentially on its graduations, it is important to select and use Verniers of known reliability. Graduations must be narrow and of uniform width and depth for accurate matching, as well as accurately spaced, if readings are to be correspondingly accurate.

Vernier Tools. — Calipers, Height Gages and Depth Gages, as well as some other tools, are available equipped with Verniers which permit reading to very small parts of an inch, customarily

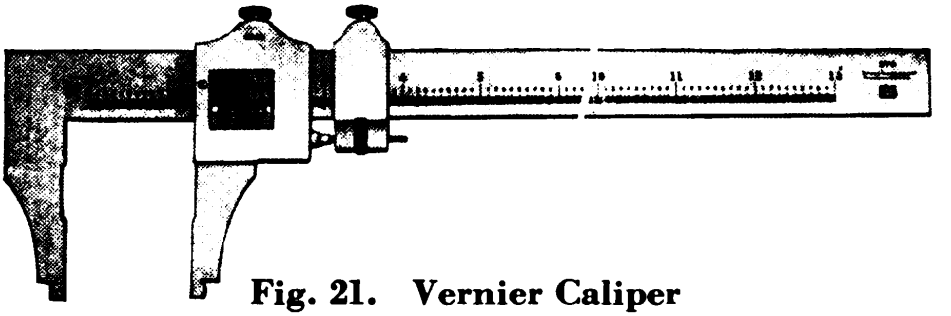


Fig. 21. Vernier Caliper

in thousandths. Such tools have the distinct advantage of taking exceedingly close measurements over a long range, as in the case of Vernier calipers from 0 to 48″, and even greater lengths, if required, in thousandths of an inch.

Vernier Calipers. — These tools are very convenient for taking both inside and outside measurements over a long range of sizes. Usually one side is graduated to take measurements outside the jaws, and the other side measurements inside the jaws, but Vernier calipers are furnished also to take measurements in both English and Metric measure and, in this case, both inside and outside measurements must be taken from one side of the caliper, as described on page 39.

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Vernier Height Gages. — These tools, Fig. 22, are particularly valuable in toolroom and for setup work. They are available for a wide range of measurements in sizes to 24″. The combination marker and extension can be used to scribe lines on the work. Offset Markers, Depth Gage Attachments and Dial Attachments are available, also, for use with Vernier Height Gages.

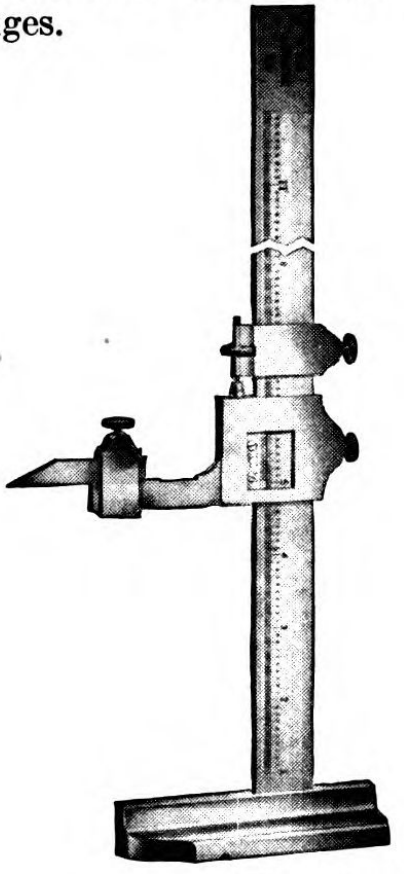


Fig. 22. Vernier Height Gage

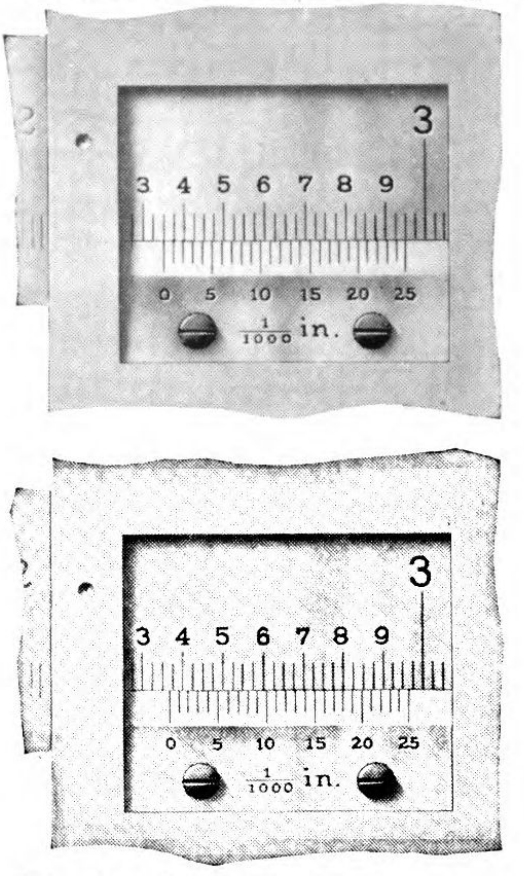


Fig. 23. Vernier Graduations English

Illustrations in Fig. 23 show the Vernier used with a scale which is graduated into 40ths or .025ths of an inch. The Vernier has 25 divisions which are numbered every 5th division and which equal, in extreme length, 24 divisions on the scale, or $24 \times 1/40'' = 24 \times .025'' = .600''$. Thus, one division on the Vernier equals 1/25 of $.600'' = .024''$. Therefore, the difference between a division on the Vernier and a division on the scale = $.025'' - .024'' = .001''$.

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When the reading is exact, with respect to the number of fortieths of an inch, the zero on the Vernier coincides with a graduation on the scale — either inch, tenth or fortieth, as the case may be. This leaves a space between lines on the scale and the 1, 2, 3, 4, 5, 6, etc., lines on the Vernier of .001″, .002″, .003″, .004″, .005″, .006″, etc., respectively, the difference increasing .001″ at each Vernier division in numerical order until, at the 25th graduation, the lines again coincide (see upper cut).

Thus, when the 1st, 2nd or 3rd, etc., line on the Vernier coincides with a line on the scale, the zero on the Vernier has moved 1, 2, or 3, etc., thousandths of an inch past the previous fortieth graduation to bring these lines together.

To read. — Note the inches, tenths and fortieths of an inch that the zero on the Vernier has moved from the zero on the scale and to this reading add the number of thousandths indicated by the line on the Vernier that coincides with a line on the scale.

Example. — The upper cut shows the zero graduation on the Vernier coinciding with a fortieth graduation on the scale (the second fortieth beyond an even tenth graduation). This indicates that the reading is exact with respect to the fortieths of an inch. The reading therefore equals 2.000″ + .300″ + .050″ = 2.350″. The lower cut, however, shows the 18th Vernier graduation coinciding with a line on the scale. This indicates that .018″ should be added to the scale reading. The reading, then, equals 2.000″ + .300″ + .050″ + .018″ = 2.368″.

Verniers with 25 divisions are used on most English measure Vernier tools but Verniers with 20 divisions are used on several types because of the smaller space available. Where 20 divisions are used the smallest scale graduation represents 1/50 or .020 of an inch.

Illustrations in Fig. 24 show the Vernier used with a scale which is graduated into 1/2 mm or .50 mm. The Vernier has 25 divisions which are numbered every 5th division and which equal, in extreme length, 24 divisions on the scale, or 24 × 1/2 mm = 12 mm. Thus, one division on the Vernier equals

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1/25 of 12 mm = 12/25 mm. Therefore, the difference between a division on the scale and a division on the Vernier = 1/2 mm − 12/25 mm = 25/50 mm − 24/50 mm = 1/50 mm or .02 mm.

When the reading is exact, with respect to the number of mm or 1/2 mm, the zero on the Vernier coincides with a graduation on the scale either mm or 1/2 mm as the case may be. This leaves a space between lines on the scale and the 1, 2, 3, 4, 5, 6, etc., lines on the Vernier of .02 mm, .04 mm, .06 mm, .08 mm, .10 mm, .12 mm, etc., respectively, the difference increasing .02 mm at each Vernier division in numerical order until, at the 25th graduation, the lines again coincide (upper illustration).

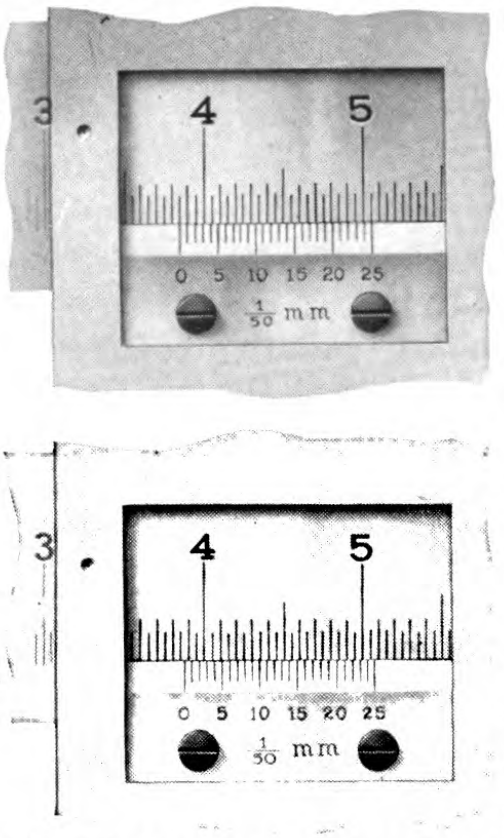


Fig. 24. Vernier Graduations Metric

Thus, when the 1st, 2nd, or 3rd, etc., line on the Vernier coincides with a line on the scale, the zero on the Vernier has moved 1, 2, or 3, etc., fiftieths mm past the previous mm or 1/2 mm graduation to bring these lines together.

To read. — Note the mm (and 1/2 mm if setting allows one), that the zero on the Vernier has moved from the zero on the scale and then add the number of fiftieths mm indicated by the line on the Vernier that coincides with a line on the scale.

Example. — The upper illustration shows the zero graduation on the Vernier coinciding with a 1/2 mm graduation on the scale. This indicates that the reading is exact with the respect to a 1/2 mm. The reading therefore equals 38.00 mm + .50 mm = 38.50 mm. The lower illustration, however, shows the 9th

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Vernier graduation coinciding with the line on the scale. This indicates that 9/50 mm or .18 mm should be added to the scale reading. The reading, then, equals 38.00 mm + .50 mm + .18 mm = 38.68 mm.

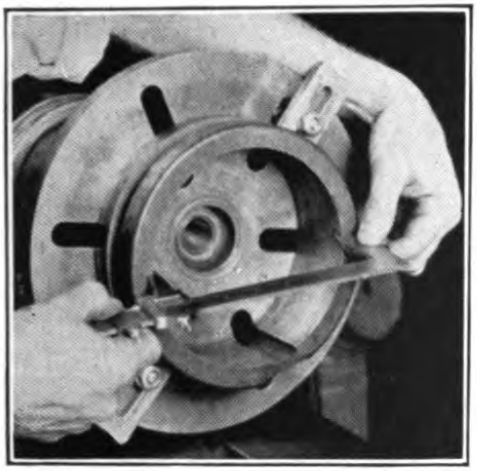


Fig. 25. Vernier Caliper in use

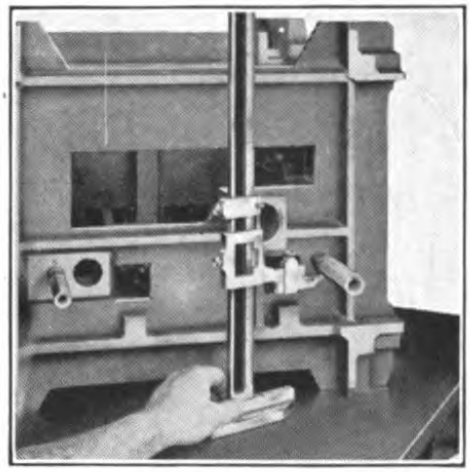


Fig. 26. Vernier Height Gage in use

How to Read Inside Measurements with a Vernier Caliper Graduated in English and Metric Measure. — For inside measurements or measurements over the nibs where both the inside and outside measurements are taken from the same side of the caliper the following amounts should be added to the reading to allow for nib thicknesses:

Size	*English Measure*	*Metric Measure*
6″ or 15 mm	Add .250″	Add 6.35 mm
12″ " 300 "	" .300″	" 7.62 "
24″ " 600 "	" .300″	" 7.62 "
36″ " 900 "	" .500″	" 12.70 "

Micrometer Height Gage. — Fig. 28 shows a height gage attachment, designed for use with an inside micrometer, and making with it a reliable micrometer height gage. The desired measuring rod is inserted through the underside of the base, and its end lined up with the base of the attachment. The chuck is then tightened and rod becomes fixed firmly in an upright position. The micrometer is then adjusted to correct

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position on the rod. Rod has series of angular grooves that allow clamping fingers on micrometer to spring in for accurate adjustment. The base has a V shaped groove on the bottom which adapts the tool for use in cylindrical work.

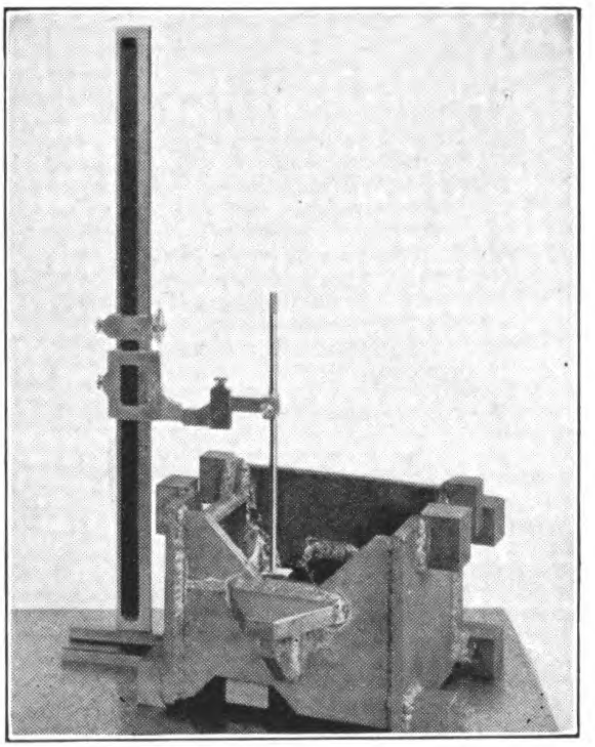


Fig. 27. Depth Gage Attachment in use with Vernier Height Gage

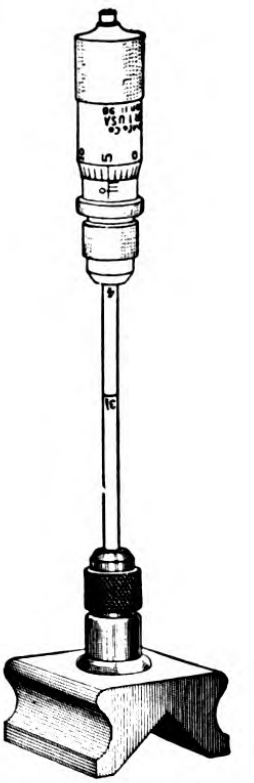


Fig. 28. Inside Micrometer with Height Gage Attachment

Depth Gages. — Depth Gages are especially handy for tool and die makers for measuring depths on work where a gage with a permanent or fixed blade can not be used. They are useful for measuring the depth of holes, recesses in dies or the distance from a plane surface to a projection. See Figs. 29 and 45. Depth Gages are available in various shapes and sizes with micrometer or Vernier graduations in either English or Metric measure.

Gages. — A gage may be any one of a variety of shapes or sizes. It is usually made of steel, hardened, ground and lapped,

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and represents a fixed dimension with which work must comply to pass inspection.

Cylindrical Plug and Ring Gages. — These gages conform in design to standards specified by the American Gage Design Committee.

The Cylindrical Plug Gages are made with separate handles and gage members which permit replacing a worn or damaged member without replacing the handles, Fig. 30. The handles are hexagonal in shape and made of aluminum alloy for lightness. Plug Gages are made in two styles: Taperlock for the smaller sizes and Reversible for the larger sizes. With the Taperlock style, one end of the gage member is ground on a taper that fits a taper hole in the handle. In the

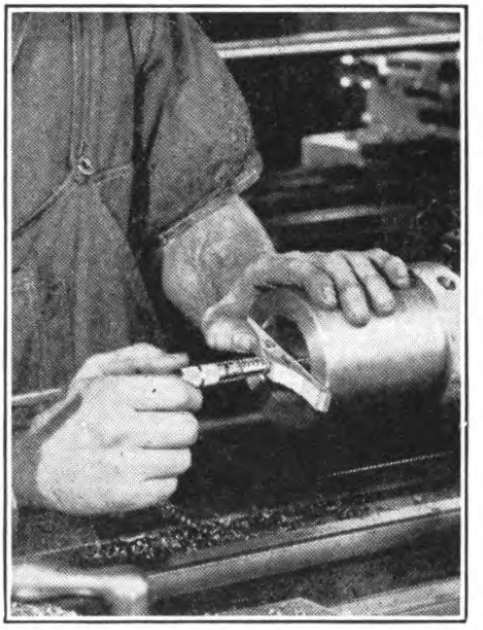
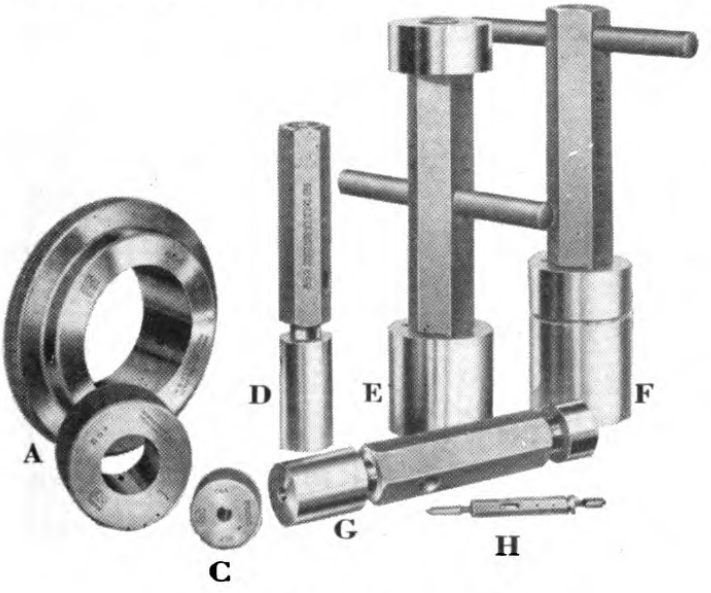


Fig. 29. Micrometer Depth Gage in use



A — Large Ring Gage — Flange Type
B — Ring Gage — Solid
C — Small Ring Gage with hardened bushing in soft body. (See page 42)
D — Taperlock handle with long member
E — Reversible handle, double end, Go and Not Go members
F — Reversible handle, single end, with Progressive member
G, H — Taperlock handle with Go and Not Go members

Fig. 30. Cylindrical Plug and Ring Gages, American Gage Design Standard

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Reversible style, the gage member is held on the end of the handle by a screw. Gages are made single end, with gaging member having a long gaging surface, with the regular " Go," gaging surface, with a Progressive gaging member (limit type) or with a short " Not Go " gaging member, and, also, double end with both Go and Not Go members. The Go member is the longer as it is subjected to more wear.

The Plug Gages are generally made in four different tolerances depending upon the work for which the gages are intended.

The Ring Gages are made in three styles, each of which includes Go and Not Go gages. Ring Gages in small sizes have a hardened, ground and lapped steel bushing in a steel body to insure a uniform hardness throughout the small inner ring, which

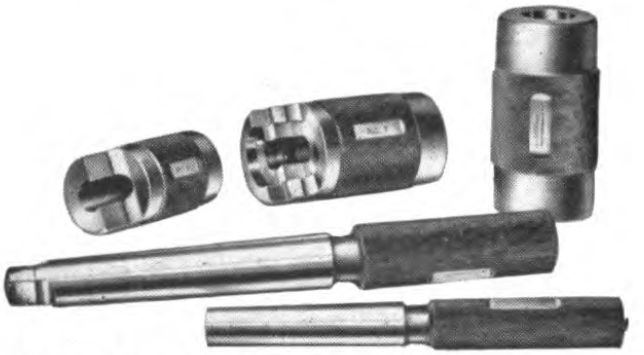


Fig. 31. Cylindrical Taper Gages

would be difficult to secure in very small gages if made solid. Not Go Ring Gages have an annular groove for identification purposes. The large sizes are made with flanges to eliminate unnecessary weight.

Cylindrical Taper Gages, Fig. 31, are made for internal and external use, also for maintaining standard taper holes in the spindles of machines and collets as well as for standard shanks of arbors, end mills, drills and for sizing standard taper reamers. They are usually made of steel, hardened, ground and lapped to size.

Standard Caliper Gages, shown in Fig. 32, are made from steel forgings carefully hardened, ground and lapped to size.

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Due to their form which combines lightness with strength they are preferable to plug and ring gages for frequent use.

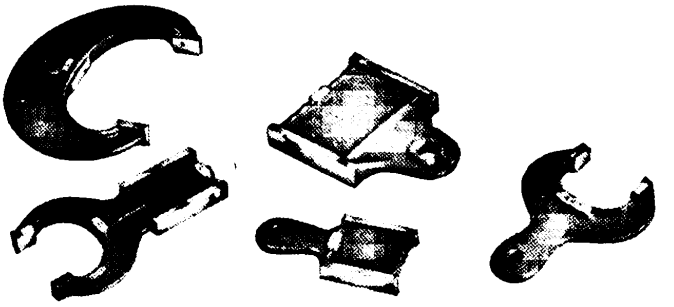


Fig. 32. Standard Caliper Gages

They can be furnished with both ends finished — one end for internal and the other for external measurements. The contact surface of an outside gage is flat, that of an inside gage is cylindrical. For convenience in handling, larger sizes are made without handle ends.

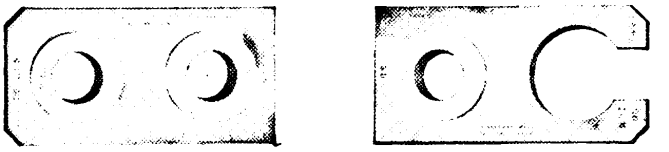


Fig. 33. Twin Ring and Combination Ring and Snap Gages, American Gage Design Standard

Limit Gages. — Limit Gages are of great advantage in saving time in testing and in insuring the accurate duplication of parts, and their use is not confined to finishing operations as they are equally valuable in checking roughing sizes. Cylindrical Plug Gages with Go and Not Go members and with Progressive members, as well as Ring Gages in Go and Not Go sizes, are convenient styles. Limit Gages are made in various shapes. A very convenient form has both sizes contained between the same jaws at one end, the larger or maximum limit at the outer end. See also Fig. 33 above. Usually one end of the gage

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(the go end) is made longer, or with bevel corners or has some distinguishing feature to identify it for quick usage.

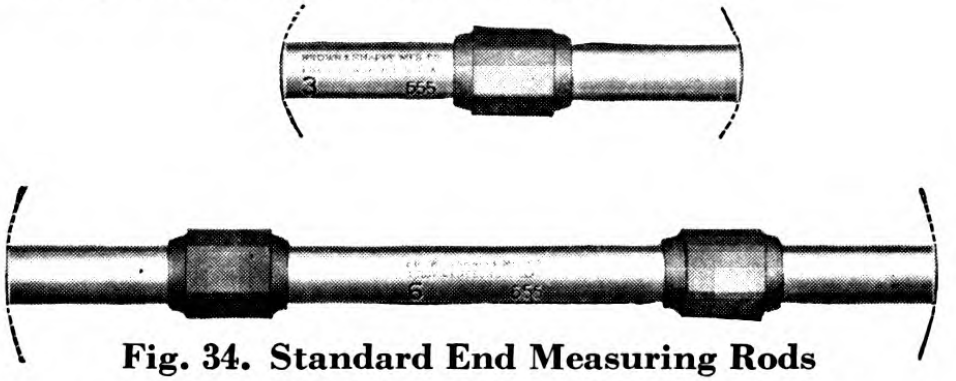


Fig. 34. Standard End Measuring Rods

Standard End Measuring Rods, Fig. 34, are made of steel, hardened on the ends and accurately ground so that the ends are spherical. They are particularly useful for measuring parallel surfaces, rings and cylinders, for setting calipers, comparing gages and for testing precision measuring tools. Small sizes have one rubber grip and larger sizes have two. The rubber grips resist the heat and moisture of the hand and prevent rods from slipping or rolling. The rods are furnished in lengths from 3″ to 23″ and in corresponding sizes in Metric measure.

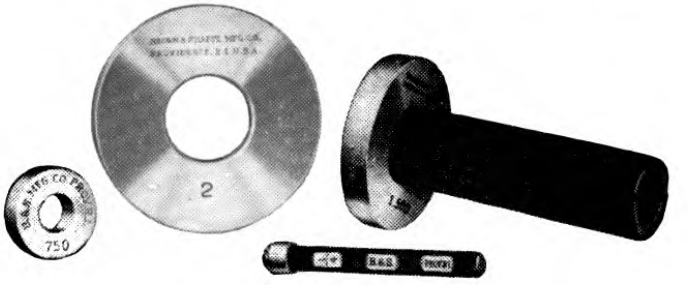


Fig. 35. Standard Reference Disks

Standard Reference Disks shown in Fig. 35 are made of tool steel, hardened, ground and lapped to size. They are for reference sizes in shop work, and for testing gages or micrometer calipers. Handles are furnished which screw into the center of the disks to preserve them from contact with the heat and moisture of the hand. These disks can be used for internal

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testing, but such a use is not recommended because used in this way they will soon become worn and inaccurate.

Taper Parallel Gages available in individual sizes or in sets, Fig. 36, are measured with an outside micrometer caliper, and are useful for determining the diameter of a hole. They are handy in a shop where it is not practicable to have a complete set of plug gages.

Special Gages. — Special gages are made in a wide variety of forms and for specialized work as the name suggests. They include gages for plate glass, lumber, railroad use, flooring, rubber rings, threads, veneers, special tapers and spline shafts. Illustrated in Fig. 37 are a few such special gages.

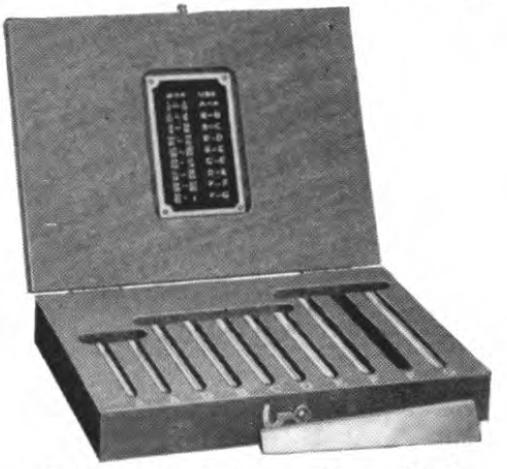


Fig. 36. Taper Parallel Gages

The manufacture of accurate gages, requires highly specialized equipment and carefully controlled conditions. Vibration and temperature fluctuations must not be evident in a gage inspection department if consistent and accurate results are expected.

In addition to the gages described in the preceding paragraphs there are many gages of a special character such as those



Fig. 37. Special Gages

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shown in Fig. 38. Here we see a representative Caliper and Wire Gage A; a Rolling Mill Gage B having a series of gage sizes used in Rolling Mills; an American Standard Wire Gage C

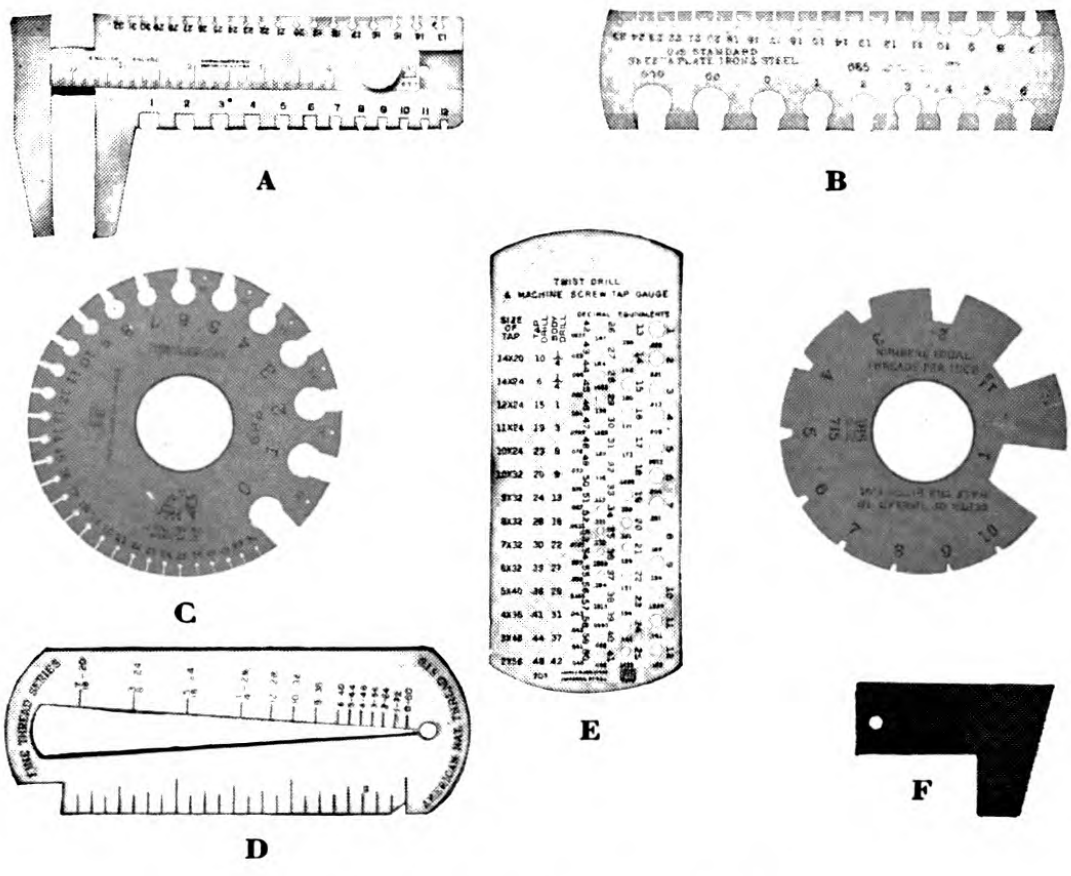


Fig. 38. Miscellaneous Types of Gages

containing a series of gage sizes for wire (such wire gages are obtainable for other gage sizes); American National Standard Screw Gage D; a Twist Drill and Machine Screw Tap Gage E; and Screw Thread Tool Gage F with Tool Setting Gage. These and other similar gages are used to simplify accurate sizing of work and materials.

Scribers. — A scriber is used to scribe lines on metal. Usually the surface has been prepared by chalk smoothed in with the hands or by a coating of copper from an application of blue vitriol (copper sulphate) to a smooth surface. A scriber is ordinarily

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used in conjunction with a straight edge, or as shown in Fig. 39 with the combination bevel for laying out angles. Several styles and sizes are available.

Center Punch, sometimes called a " prick " punch, is used to make points on metal. Used for this purpose it should be held as nearly vertical as possible when struck with the hammer. Center punches are usually knurled in order to afford a good grip; both ends should be tempered and ground to the proper angle.

The Automatic Center Punch shown below in Fig. 40 has a striking mechanism enclosed in the knurled handle. A downward pressure releases the striking block and makes the impression. The length of the stroke is adjustable for different kinds of work, and the points can be taken out for grinding or replacement. Automatic Center Punches are very convenient to use and help in accurately locating points as the center punch point can be easily held in desired position while pressure is being exerted.

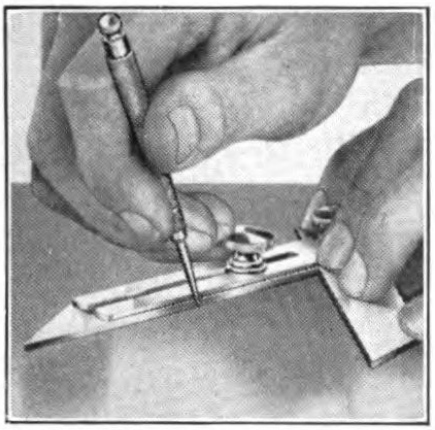


Fig. 39. Scriber and Combination Bevel in use

Straight Edges, Fig. 41, are convenient for laying out lines on full size drawings or on metal. They are made of the highest grade tool steel in several styles, with square or beveled edges, depending on the use. The Toolmakers' Knife Edge Straight Edges are intended for work requiring extreme accuracy. They have an edge of semi-circular form to insure line contacts when testing. These straight edges are subjected to a seasoning process to prevent warping.



Fig. 40. Center Punches

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Universal Surface Gage, Fig. 42, is a very useful and accurate tool in layout work and for lining up castings on a leveling plate or for leveling work on a machine table. An approximate adjustment can be made, and then, after tightening the knurled nut at the boss on the base, the fine adjustment can be used to obtain the exact setting. The nut for fine adjustment can be adjusted with the same hand that holds the surface gage. Two gage pins in one end can be pushed down and used against the edge of a surface plate, or the side of a T slot. A V shaped groove in the bottom adapts the gage for cylindrical work. The spindle swivels and can be clamped in practically any position.



Fig. 41. Beveled Steel Straight Edge

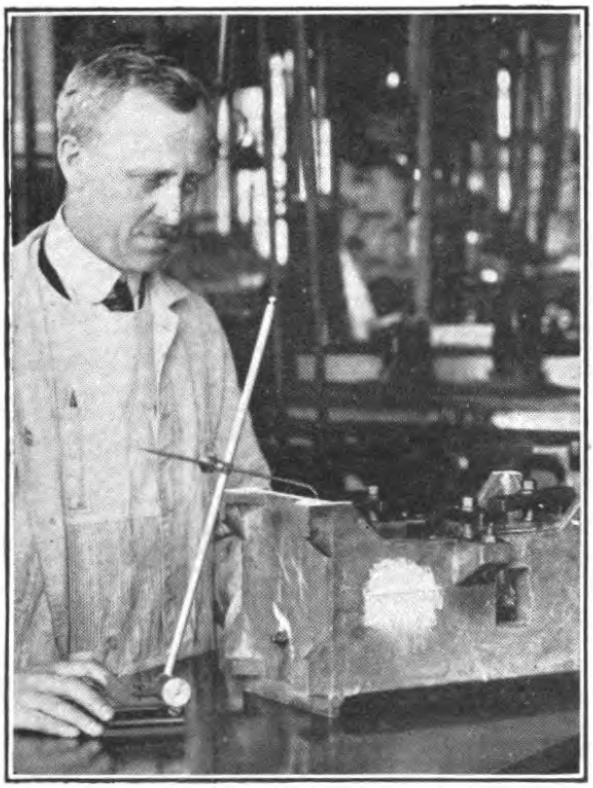


Fig. 42. Universal Surface Gage in use

Screw Drivers are of various lengths and weights depending upon the class of work for which they are used. The end should be hardened and tempered .65 carbon steel with sides ground parallel at the end and the edges somewhat rounded so as to fit snugly into the slot of the screw without damaging it.

The Machinist's Hammer for chipping and general use should weigh from 12 to 24 ounces. Some are made of crucible steel, others of forged steel, but a hammer made of .95 carbon steel with both face and peen hardened and tempered is quite

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suitable for ordinary work. The handle should be of hickory or similar wood, long enough to suit the individual, and with flexibility enough under the head to relieve the wrist from the shock of the blows. The face should be crowned slightly.

The Level is used to determine the truth of horizontal or vertical lines. The frame may be of either wood or metal. It carries two tubes, sometimes three, that are partially filled with alcohol leaving a small bubble in each. The tube for horizontal lines is at a right angle with the one for vertical lines. When the bubble is in the middle of the tube and exactly halved by the indicating line on the tube, the truth of the line may be said to be established.

The Plumb Bob, see Fig. 43, is used to establish vertical lines. The type shown in the cut is made from a solid steel rod, drilled out and filled with mercury. The point is hardened and both point and body are ground.



Fig. 43. Plumb Bob

Combination Squares or Sets. — These tools are almost indispensable for either machine work or for laying out work. A combination set is shown in Fig. 44. They have a multitude of uses, some of which are shown in Figs. 45, 46, 47 and 48. A combination set includes the blade, the protractor, square head and center head, while a combination square includes only the blade and the square head with or without the center head. Protractors and square heads, except in smaller sizes of square heads, are fitted with a level.

The reversible bolt permits either side of the blade to be used, as desired. The knurled tip on the bolt permits the bolt to be reversed without removing it from the head.

The Protractor has a head with a revolving turret graduated to 90° either side of zero. By means of it any angle can be found. The head is adjustable

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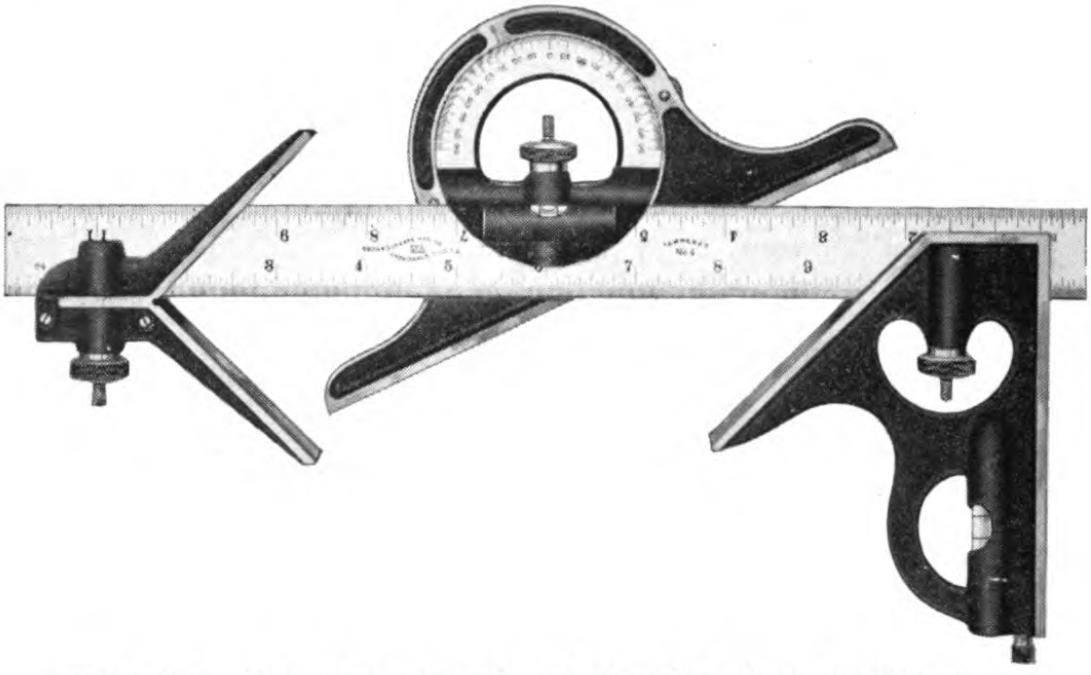


Fig. 44. Combination Set including Square Head, Center Head and Protractor

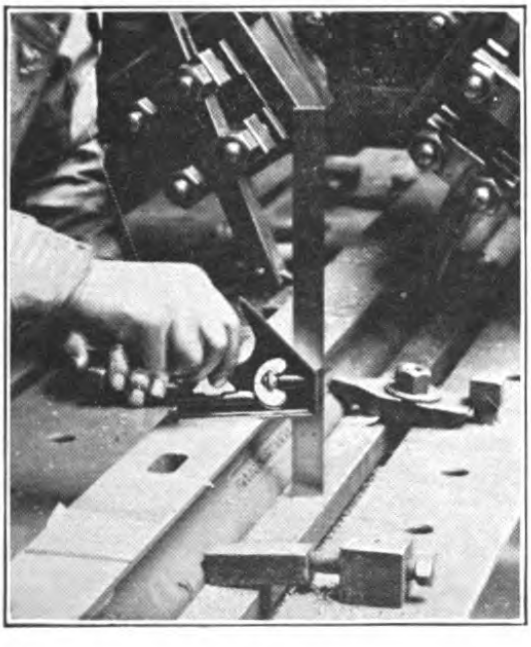


Fig. 45. The Combination Square may be used as a Depth Gage

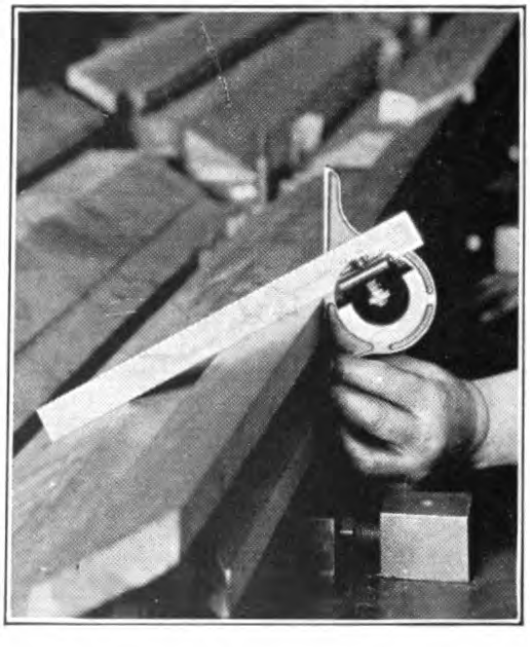


Fig. 46. An Angle can be quickly determined with a Protractor

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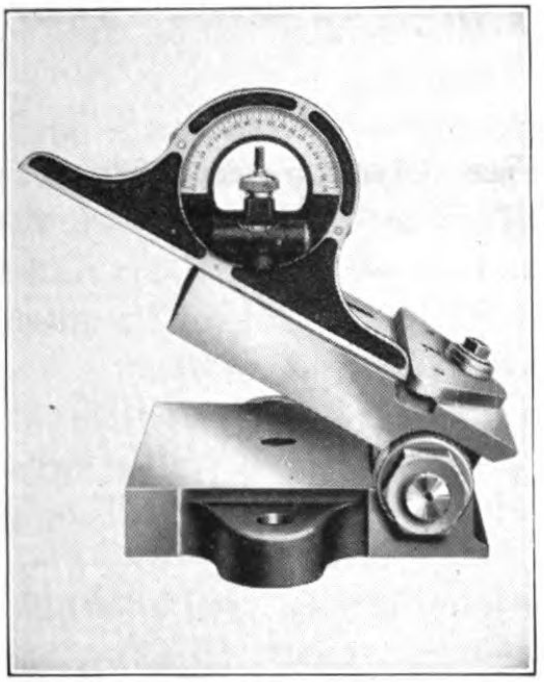


Fig. 47. An Angle Block can be set with a Protractor

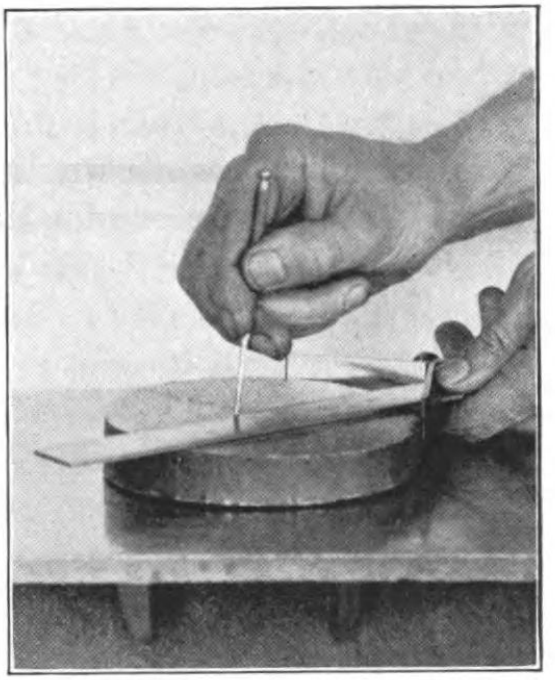


Fig. 48. Locating the Center of a Piece of Stock with the Center Head and Scale

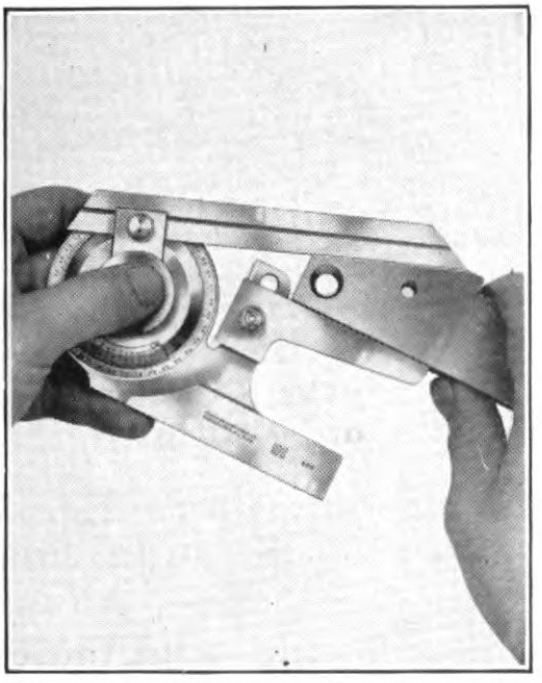


Fig. 49. Checking an Angle with a Bevel Protractor

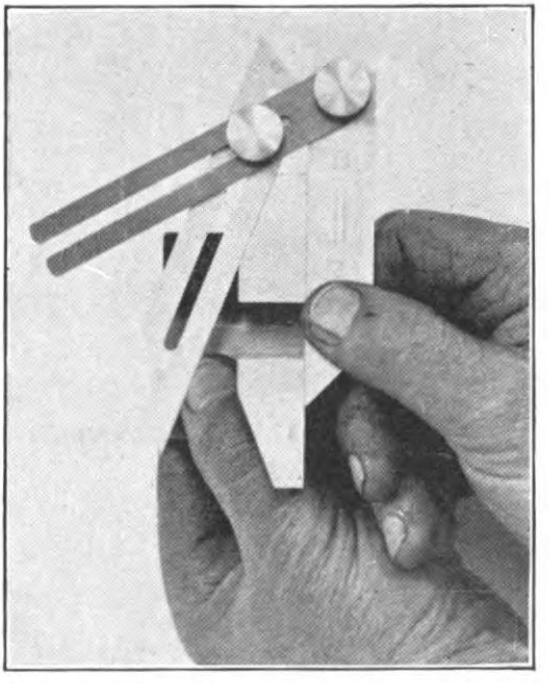


Fig. 50. Checking the Angle of a Piece of Work with a Combination Bevel

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along a tempered and graduated blade similar to the one furnished with the tools referred to previously.

The Universal Bevel Protractor with the acute angle attachment as shown in Figs. 49 and 51 is designed for all classes of work where angles are laid out. One side of the tool is flat which permits it to lie flat on work or paper. The dial is graduated to degrees around the entire circle. The Vernier reads to 5 minutes or to 1/12 of a degree. The blade is about 1/16″ thick, and can be moved back and forth throughout its entire length, or clamped independently of the dial. With the acute angle attachment, shown in use in Fig. 49, extremely small angles can be laid out easily.

The Combination Bevel shown in Fig. 52 is used to transfer or check up angles or angular surfaces. Figure 50 shows this tool in use.

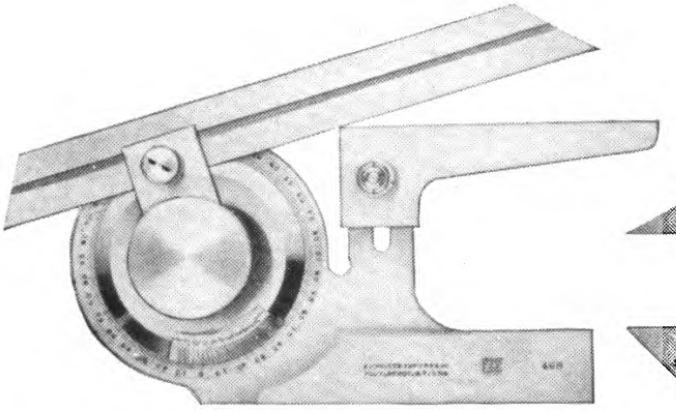


Fig. 51. Universal Bevel Protractor with Acute Angle Attachment

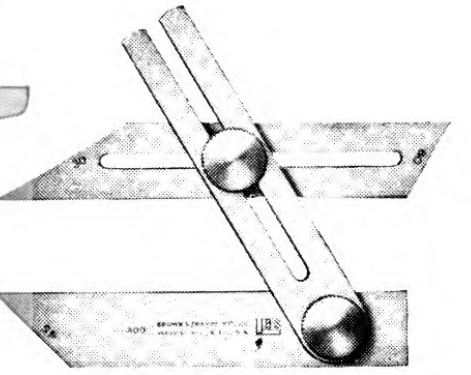


Fig. 52. Combination Bevel

Principle of the Vernier used on a Protractor. — Fig. 53 shows the Vernier used with a dial accurately graduated to 360°. The Vernier is divided into 24 spaces and has 12 spaces each side of zero. When the reading is such that the zero on the Vernier coincides with the zero on the dial, then 12 divisions, or from 0 to 60 on the Vernier equal 23 divisions, or from 0° to 23° on the dial. It follows, that since 12 divisions of the Vernier equal 23

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divisions of the dial, then 1 division of the Vernier must equal 1 11/12 divisions of the dial, or 1 division on the Vernier takes up 1/12° or 5 minutes less space than 2 divisions of the dial, and every 3rd division on the Vernier is numbered 15, 30, 45 and 60, both right and left, from a basis of zero.

When the zero on the Vernier exactly coincides with a graduation on the scale, the reading is in exact degrees. When the zero graduation of the Vernier does not exactly coincide with a graduation on the dial, the graduation that does coincide with a dial graduation indicates the number of 12ths of a degree or 5 minutes to be added to the whole degree reading.

To Read. — Read off directly from scale the number of whole degrees between 0 on dial and 0 on Vernier. Then count, in the same direction, the number of divisions from the 0 of the Vernier to the first line on Vernier that coincides with a line on the dial. As each division on Vernier represents 5 minutes,

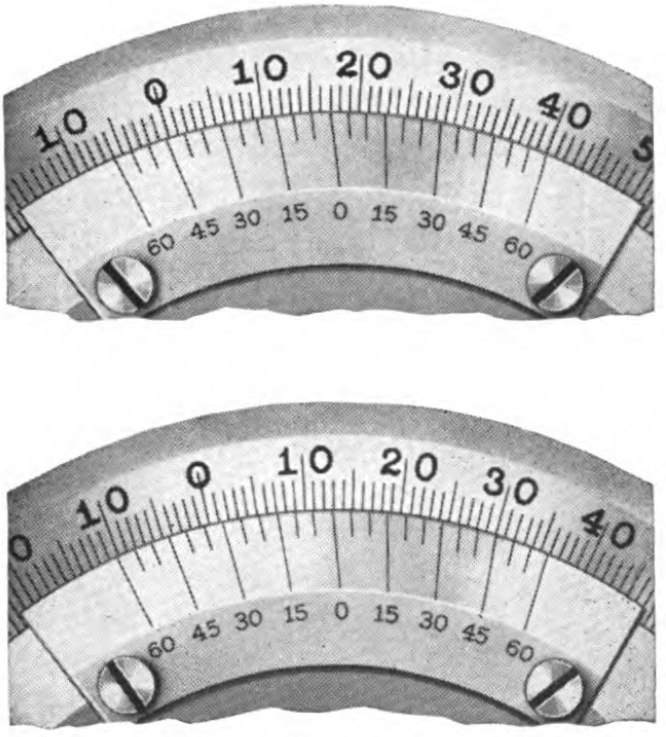


Fig. 53. Vernier Reading on a Bevel Protractor

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the number of these divisions multiplied by 5 will be the number of minutes to be added to the whole number of degrees.

Example. — Lower illustration, Fig. 53, shows zero on Vernier between 12 and 13 on dial. Counting to the right from zero on dial, the zero on the Vernier has therefore moved twelve whole degrees. In the same direction the 10th line of the Vernier, representing 50 minutes (50′), is the line which exactly coincides with a line on the dial. We, therefore, have 50 minutes as indicated by the Vernier, to be added to the reading of twelve degrees on the dial. The reading, then, is 12° 50′.

Since the divisions, both on the dial and on the Vernier, are numbered both to the right and left from a basis of zero, any size angle can be measured, and the readings on the dial and on the Vernier, are taken either to the right or left, according to the direction in which the zero on the Vernier is moved.

It is extremely important that tne use of a bevel protractor and the relationship of the position of the blade to the reading be thoroughly understood before angles are measured and computed with this tool. Because of the many different angles which may be computed with the tool and the many combinations of settings and adaptations of the tool and blade for angular measurements, it is essential that the user understand that the reading which is taken represents the angle measured and not its complement or supplement (see pages 105 to 109).

The graduations on the bevel protractor have been designed to simplify the readings as much as possible but angular measurements can be much more deceptive than measurements of linear dimensions. One of the best ways for the user to be sure of his measurements with the protractor is to study its design and then become more familiar with it through a little practice with this tool.

Other Tools such as the thickness gage, toolmakers' buttons, screw pitch gage, screw thread micrometer caliper, three wire thread measuring fixture and indicators are described in succeeding chapters.

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Geometric Problems for Layout Work

To draw through a given point, as *A*, a line parallel to a given line, as *BC*. (Fig. 54.) Using *A* as a center and with any convenient radius, as *AD*, draw arc *ED* to intersect line *BC*. Now with *D* as a center and with the same radius, describe arc *AJ*. With *D* as a center and a radius equal to *AJ* describe an arc intersecting *DE* at *K*. Draw *AK*. *AK* is parallel to *BC*.

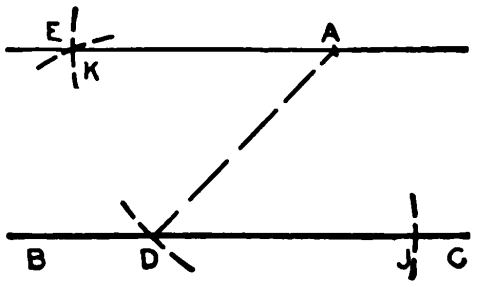


Fig. 54

To draw a line parallel to a given line and at a given distance from it. (Fig. 55.) Let *AB* be the given line and *AD* the distance. With a radius equal to *AD* and with *A* and *B* as centers draw arcs as at *D* and *C*. Draw line *DC* tangent to these arcs. *DC* is the required line parallel to *AB* and at *AD* distance away from *AB*.

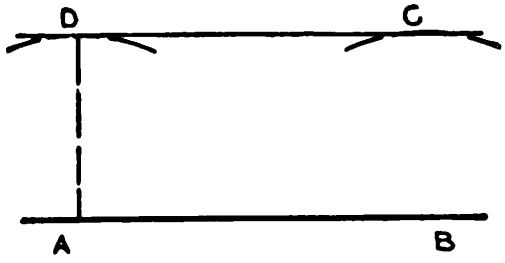


Fig. 55

To erect a perpendicular line to a given line from a given outside point. (Fig. 56.) Let *BC* be the line and *A* the point. With *A* as a center and a radius greater than the distance to *BC*, describe arc *OK*. With *O* and *K* as centers and a radius greater than half *OK*, describe two arcs intersecting at *D*. *AD* will be perpendicular to *BC*.

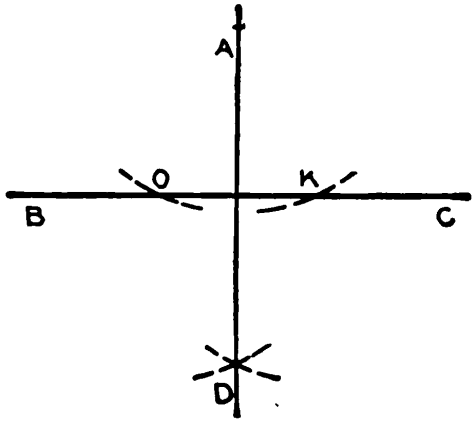


Fig. 56

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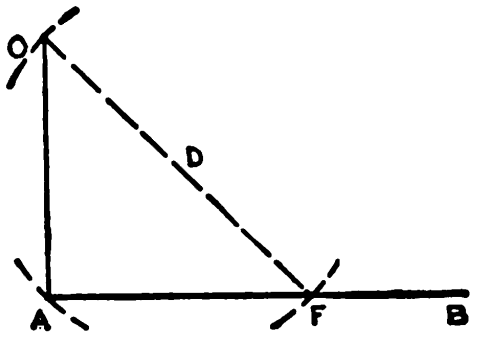


Fig. 57

To erect a perpendicular at the end of a given line. (Fig. 57.) Let *AB* be the line. From a point outside the line *AB*, as at *D*, and with a radius equal to the distance from *D* to *A* draw the arc *OAF*. From *F*, where the arc intersects the line, draw a diameter through *D*. Where this line intersects the arc at *O*, drop a line to *A*. *OA* is the required perpendicular.

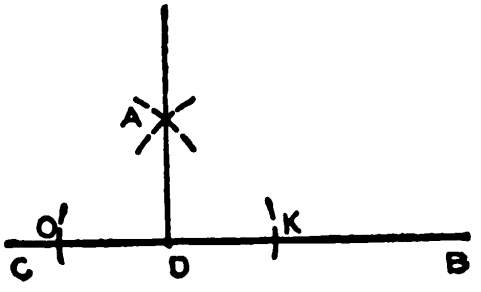


Fig. 58

To erect a perpendicular to a given line at a given point. (Fig. 58.) Let *CB* be the given line and *D* the given point. With *D* as a center and any convenient radius draw arcs to intersect *CB* at *O* and *K*. With *O* and *K* as centers and with a radius greater than the arc used before, draw arcs that intersect as at *A*. Draw line *AD* which is the desired perpendicular.

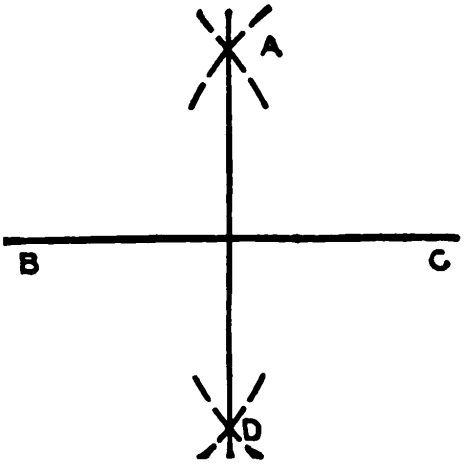


Fig. 59

To bisect a given line. (Fig. 59.) Let *BC* be the line. With *B* as a center and with a radius greater than half of *BC* draw an arc *AD* and with *C* as a center and with the same radius draw another arc intersecting the first. Draw *AD*. *AD* is the perpendicular bisector of line *BC*.

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To bisect a given arc. (**Fig. 60.**) Let *AKB* be the given arc. With *A* as a center and a radius greater than half of chord *AB* describe an arc and with *B* as a center and with the same radius describe an arc intersecting the first at *C* and *D*. Draw a line connecting points *C* and *D* and where this line cuts the arc *AKB*, it also bisects it, as at *K*.

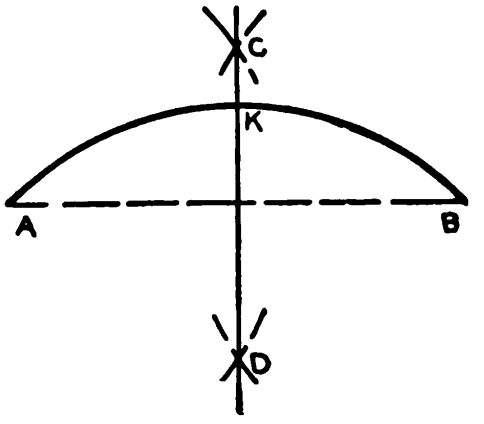


Fig. 60

To find the center of a given circle or arc. (**Fig. 61.**) Let *BAC* be the given arc. Take convenient points such as *D*, *A*, and *E* on the arc. Bisect arcs *DA* and *AE* (see previous problem). The point where the bisecting lines intersect as at *O* is the center of the arc or circle.

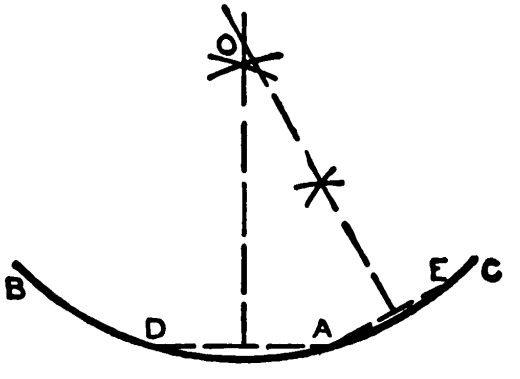


Fig. 61

To construct a square on a given line. (**Fig. 62.**) Let *AB* be the line. Erect a perpendicular to *AB* at *A* (see Fig. 57), and on this perpendicular lay off a distance *AD* equal to *AB*. With *D* and *B* as centers and with a radius equal to *AB* draw arcs that intersect as at *E*. Draw *BE* and *DE* which completes the desired square.

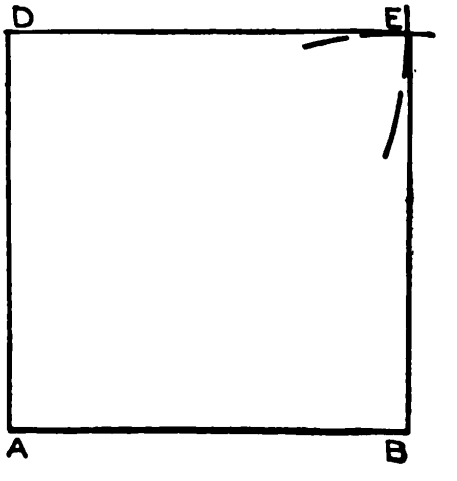


Fig. 62

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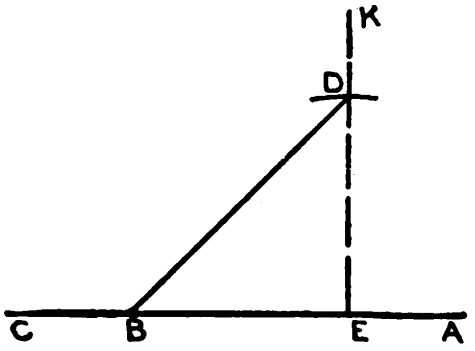


Fig. 63

To construct an angle of 45° at a given point on a given line. (Fig. 63.) Let *CA* be the line and *B* the point. Erect a perpendicular at any convenient point on *AB* as at *E*. On this perpendicular *EK* lay off a distance equal to *EB*, as *ED*. Draw *BD*. Angle *DBE* is an angle of 45°.

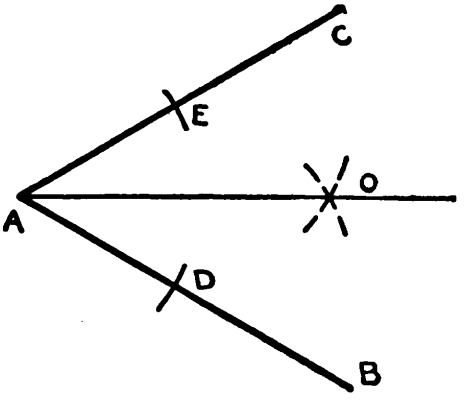


Fig. 64

To bisect a given angle. (Fig. 64.) Let *BAC* be the angle. With *A* as a center and a convenient radius draw arc as *ED*. Then with *E* and *D* as centers and with a radius more than half the distance between *E* and *D* describe arcs that intersect as at *O*. Draw line *OA* which bisects the angle.

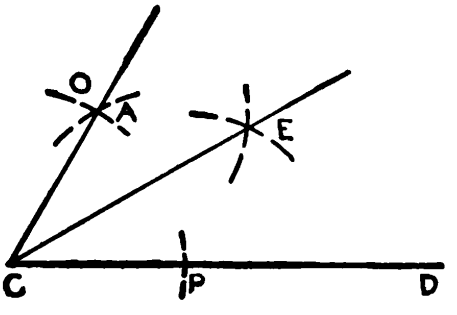


Fig. 65

To construct an angle of 60° at a given point on a given line. (Fig. 65.) Let *CD* be the line and *C* the point. Using *C* as a center and with any convenient radius, describe arc *OP*. Now with *P* as a center and with the same radius describe another arc cutting the first as at *A*. Draw *CA*. Angle *ACD* is an angle of 60°.

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To get an angle of 30° at the same point bisect angle *ACD* (see previous problem). Then angle *ACE* and angle *ECD* are angles of 30°.

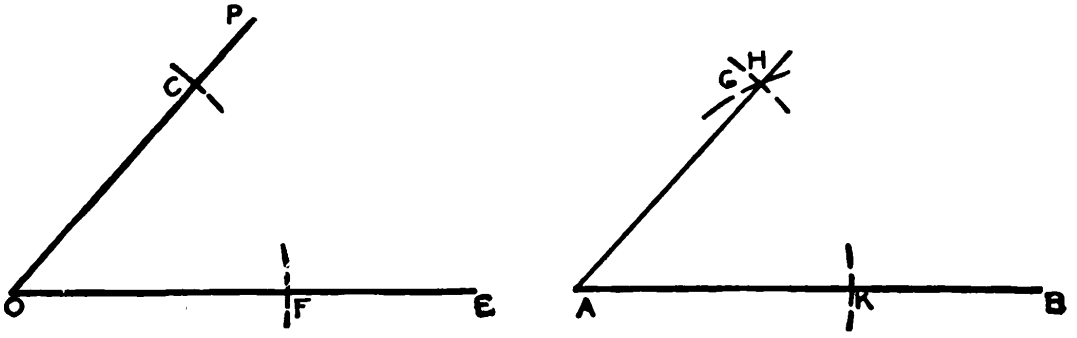


Fig. 66

To construct at a given point on a given line an angle equal to a given angle. (**Fig. 66.**) Let *POE* be the given angle, *AB* the given line, and *A* the point.

With *O* as a center and with a convenient radius describe arc *CF*. With *A* as a center and with the same radius describe arc *GK*. With *K* as a center and with a radius equal to *FC* describe an arc intersecting *GK* at *H*. Draw *AH*. *HAB* is the desired angle.

To Obtain Diameter for Finishing Square or Hexagonal. — When finishing square *the diameter is obtained by multiplying the side of the square by 1.414.* In Fig. 67, $A \times 1.414 = D$.

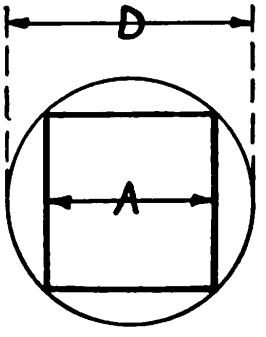


Fig. 67

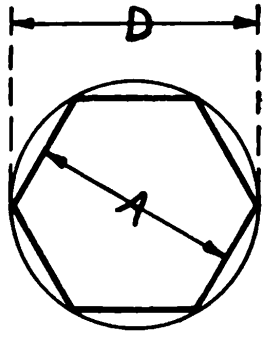


Fig. 68

When finishing hexagonal *the diameter is obtained by multiplying the distance across the flats by 1.155.* In Fig. 68, $A \times 1.155 = D$.

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CHAPTER III

Chipping, Filing and Bench Work

In the old days, chipping and filing were very important operations. Even today, although the development of machine tools has eliminated much of such hand work, the apprentice should know the correct methods to use. Watch any "old-timer" and it will appear readily that there is one right way and many wrong ways to chip or file. Chipping, especially, can become easily a "mussed-up" operation unless one knows just how to go about it.

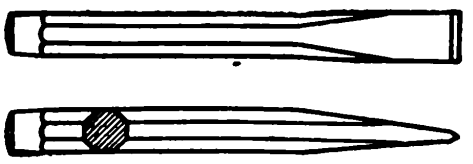
The chipping hammer should balance well and weigh from one to two pounds. In length, the hammer should suit the arm of the man swinging it, and be thinned down under the head for flexibility and to relieve the wrist from the shock of the blows.

Chipping chisels, Fig. 69, are made of alloy steels such as silicon molybdenum, silicon molybdenum vanadium or chrome vanadium having a carbon content between .50% and .60%. They are forged at 1900° F to 2100° F and then normalized to about 1650° F. The chipping ends usually are oil hardened and drawn to about 350° F. The head ends are tapered to a smaller diameter than that of body and should be oil hardened and drawn between 900° F to 1000° F. If head ends are too hard, hammer blows may cause flaking and, if too soft, "mushrooming" will result.

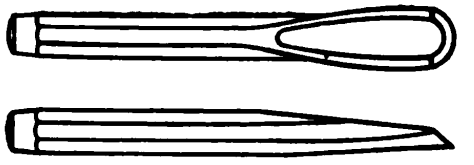
The names of the different kinds of chisels indicate the shape of their cutting edges and their use. The flat chisel is the most frequently used in chipping operations. The edges of flat and cape chisels should be ground straight across and to an acute angle but not to an angle that will prove too sharp to allow the chisel to stand up under the work in hand. An angle of 60° to 70° for cast iron; 50° to 60° for steel; 40° to 50° for brass; and about 35° for the softer metals like babbitt, copper, and lead, will work out well in practice.

The hammer should be held near the end of the handle.

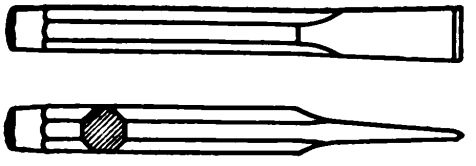
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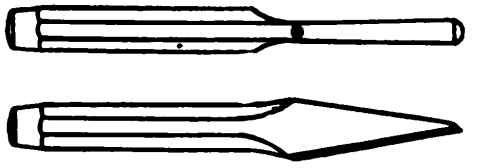
Cold Chisel



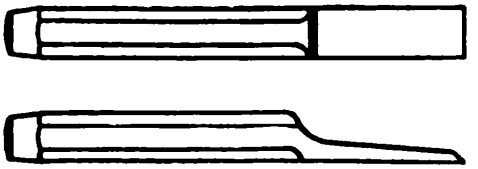
Large Round Nose Chisel



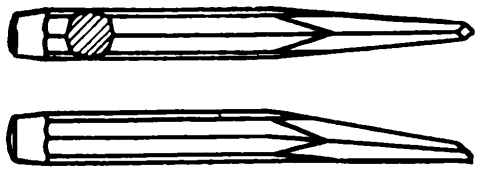
Improved Chipping Chisel



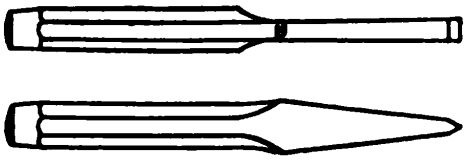
Small Round Nose Chisel



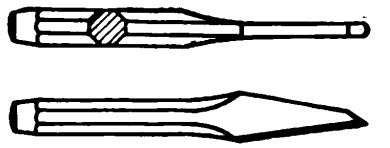
Side Chipping Chisel



Diamond Point Chisel



Cape Chisel



Center Chisel

Fig. 69. Types of Chisels

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Swing it with a free forearm movement, over the shoulder. Hold the chisel at the approximate angle shown in Fig. 70, and not too tightly. Keep it against the work. Keep the eyes on the point of the chisel — not on the head . With practice the length of the swing and force of the blow will instinctively



Fig. 70. Correct Position while using the Hammer and Chisel

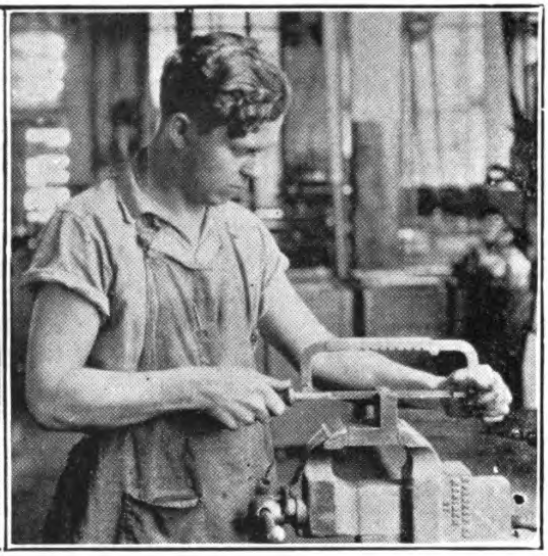


Fig. 71. Correct Position while using the Hack Saw

regulate themselves to the size of the chip. If the point of the chisel runs up out of the work, elevate the head, or, on the other hand, if the point digs in too deep, lower the head. A pneumatic chipping hammer should be used whenever it is practicable.

Hack Saw. — The hand hack saw consists of an adjustable frame and a narrow, hardened steel blade, Fig. 72. The frame sometimes has several positions of adjustment to accommodate blades of different lengths. It also has a means for putting the blade under tension by turning a wing nut or the handle. In addition, the blade can be set at a right angle to the frame so that a cut can be made close to a shoulder.

The hack saw blade should be inserted in the frame with the teeth pointing away from the handle and the handle or wing

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nut should be screwed tight enough to put considerable tension on the blade. In using the hand hack saw it should be held in about the same manner as a file. It works in about the same way except that care must be exercised not to bear down too much on the blade, lest it break. The work of cutting is done on the push stroke; upon the return stroke the saw should be lifted sufficiently to take the weight off the blade without actually lifting it from the work. It helps, on starting a cut, to make a notch with a file at the desired point.

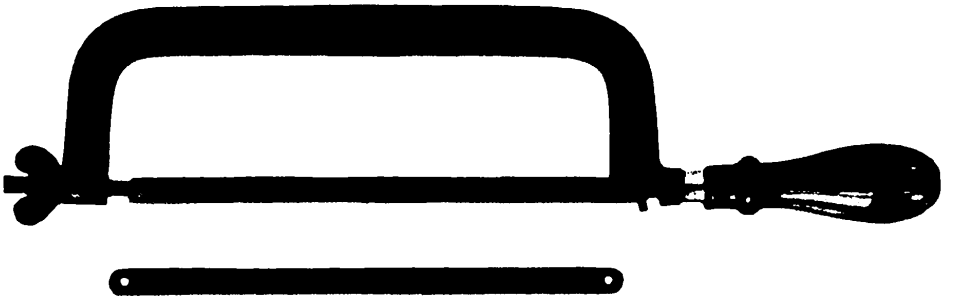


Fig. 72. Hack Saw and Blade

The hand hack saw is used dry to cut off soft metals, for slotting and for similar work. Under ordinary conditions a cutting stroke of sixty to a minute should be maintained. On the other hand, a power hack saw cutting soft steel may deliver one hundred strokes a minute. Speaking in general, for ordinary work, blades should have about 14 teeth to the inch; for cutting sheet stock or tubing, about 24 teeth to the inch.

Hack saw blades are made in a variety of styles for specific jobs and it is well to follow the instructions furnished by hack saw blade manufacturers when selecting a blade for the power saw or the hand frame.

Files and Filing. — As a chisel may be called a roughing tool, so a file may be called a finishing tool, and in the hands of an experienced and careful workman the file is capable of very fine work, both in degree of accuracy and quality of finish.

To start with, it is well for the apprentice to get a clear idea of the different kinds and names of the files. There are two

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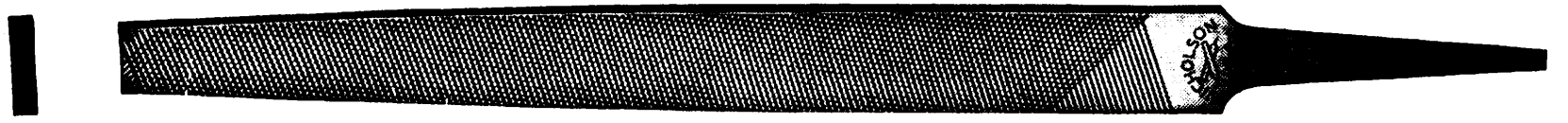


Fig. 73. Flat File. For cutting and shaping metal surfaces. Double cut bastard generally used

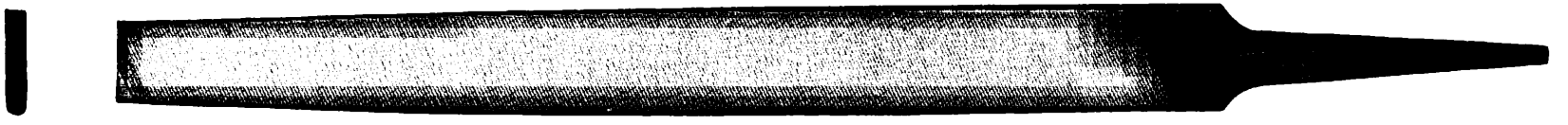


Fig. 74. Mill File. For sharpening mill saws and finishing metal surfaces. Single cut, mostly bastard



Fig. 75. Slim Taper File. Used by carpenters for sharpening saws. Single cut



Fig. 76. Round File. Taper. For enlarging round holes and shaping internal curved surfaces. Mostly bastard cut



Fig. 77. Square File. Used principally for enlarging apertures of rectangular shape. Double cut bastard

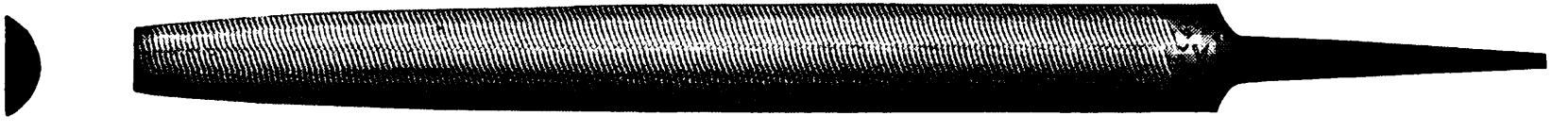


Fig. 78. Half Round File. Taper. Used for concave or irregular surfaces. Double cut, mostly bastard

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general classes: hand files and mill files. The hand file provides a clearance for the chips by the curvature of its surface. The mill or lathe file is flat and should never be used on flat work. With this file chip clearance is provided by the curvature of the work. ' A file is usually described by its length (not including the tang), its shape, and its cut (the character and coarseness of its teeth). Files are made in various shapes such as flat, round, square, triangular and half-round.

They are cut in three different ways: single cut, double cut, and rasp. The single cut file (or " flat," as those with coarser teeth are called) has rows of parallel teeth cut at an angle of from 65° to 85° with the length of the file, depending upon the character of the work for which it is to be used. The double cut file has two series of parallel teeth which cross each other. When the file is to be used for general purposes one row is cut at an angle of from 40° to 45°, the other row 10° to 80° and finer than the first row. The rasp cut file has its teeth disconnected; they are raised by a punch.

The coarseness of files is designated by the following terms: dead smooth (applied to double cut files only), smooth, second cut, bastard, coarse, and rough.

Swiss pattern files are extra fine. They are numbered: 00, 0, 1, 2, 3, 4, 5, 6, 7, and 8. No. 00 is the coarsest.

The safe edge of a file is the edge without teeth. File cards, made like a wire brush, are used to clean dirt and chips from the teeth. Oil or grease can be removed from a file by smoothing chalk over the teeth and then cleaning it out with the file card or a file tang. Chips can be prevented from clogging the teeth to some extent by filling the spaces with chalk. Any chip that can not be removed by the file end or file card can usually be dislodged by rubbing a piece of soft iron or copper along the teeth (never use hardened steel).

Filing. — In filing, the proper height for the work is about on a line with the elbows. Heavy filing can be done with greater ease if the work is lower than this height and finer filing often re-

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quires that it be much higher. The position of the body and the manner of holding the file should conform to the following rules: place the feet a natural distance apart in order to distribute the weight of the body evenly. (See Fig. 79.) Hold the file handle with the thumb up and with the palm of the other hand resting on and grasping the end of the file. In pushing the file across the work let the movement of the body correspond in an even, regular manner. The file does its work on the forward motion; relieve the downward pressure on the backward stroke without lifting the file from the work.

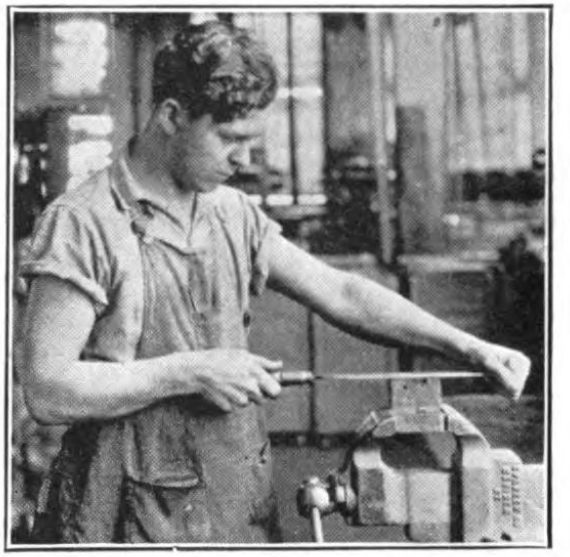


Fig. 79. Correct Position while Filing

Do not brush chips from the work with the palm of the hand; grease or moisture will reduce the " bite " of the file.

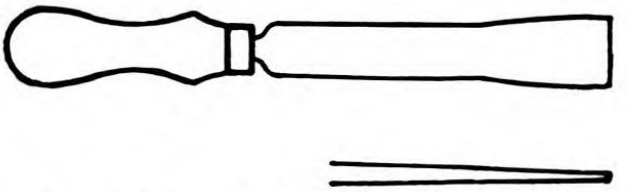


Fig. 80. Top and side view of a Flat Scraper for Scraping Flat Surfaces

Draw-filing removes very little stock; it is essentially a method for improving the finish of the work. In draw-filing the file should be held at an angle of 10° to 80° with the direction of the movement. Push and pull the file across the work.

Scraping. — In spite of the great improvement that has been made in recent years in machine tools and methods of

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doing work, there has not been, so far, any mechanical process devised to take the place of hand scraping, Fig. 81.

To become a good scraper hand requires experience, although the principle is very simple. It consists simply in reducing the

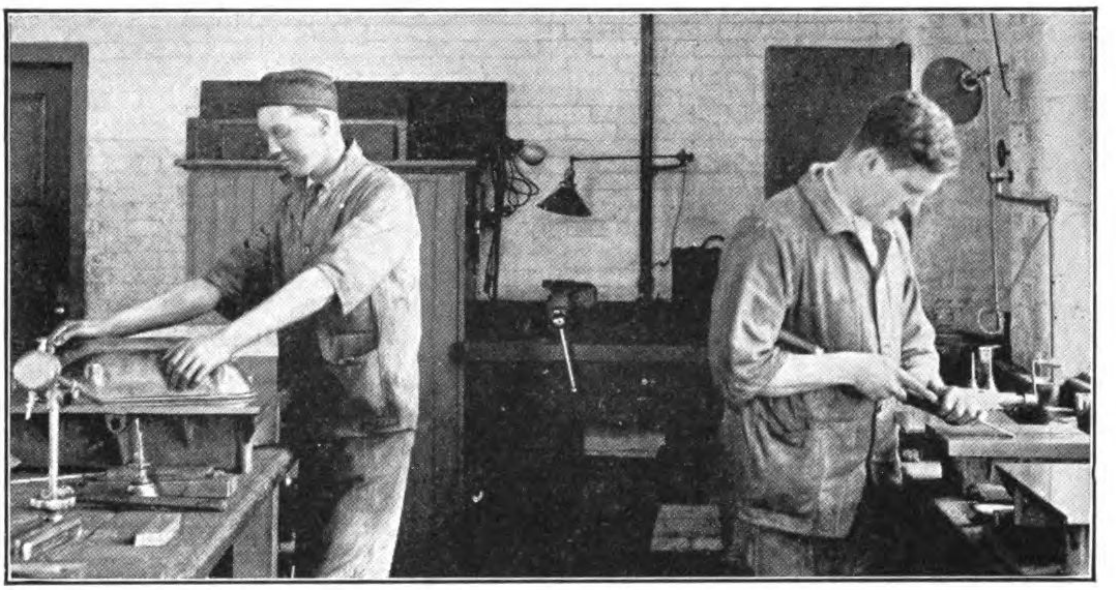


Fig. 81. Left — Marking the Work on a Surface Plate. Right — Finish Scraping or "Frosting" a Surface Plate

high spots on the surface of a piece of work, scraping from different angles as the work progresses, until the surface has a uniform bearing when in contact with the piece that is used as a standard. Ordinarily the standard used is a surface plate or straight edge, but it might be the spindle of a machine or a finished piece of work of any shape that requires a uniform bearing on the surface of another.

About the only tools and accessories needed in scraping are a surface plate for flat surfaces or a spindle or standard for cylindrical work, a scraper, an oilstone of good quality, marking paint of either Venetian Red or Prussian Blue of the consistency of putty, and a bristle brush.

Standard surface plates, Fig. 84, and straight edges are available in various shapes and sizes. They are usually of seasoned, hard, close grained cast iron, reinforced by ribs cast into their

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structure. The ribs give added strength to the plate and help resist any tendency of the surface to get out of line while in use. Every surface plate should have a cover to protect its surface.

A scraper should be tempered "glass hard" with sides ground, edges smooth, and with the end slightly rounded. In use, it should be held at an angle with the work and it should be pushed forward, with a downward pressure, a distance about equal to its width. Experience soon teaches the proper angle at which the tool should be held and what pressure to exert in order to remove metal with facility. Old files, flat and half round, can be readily converted into scrapers by first annealing the files, grinding off the teeth, and then forging to a suitable shape and thickness, and then rehardening, tempering and sharpening.

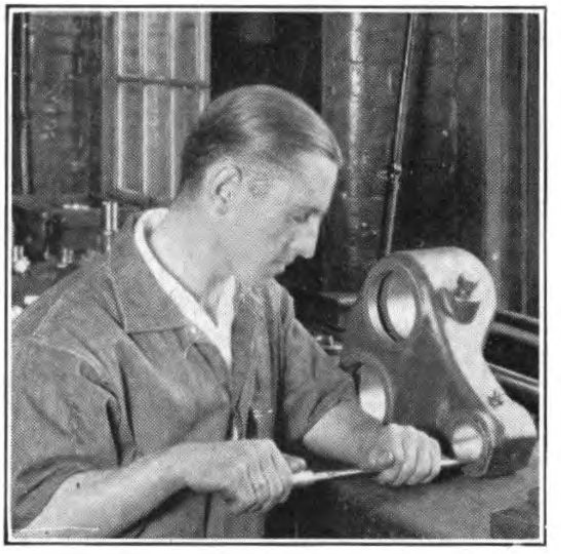


Fig. 82. Scraping a Bushing for Accurate Bearing Fit

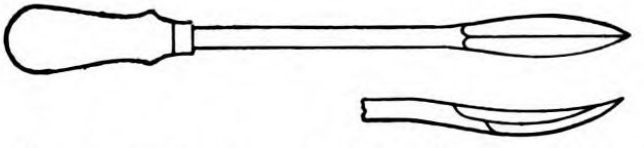


Fig. 83. Top and Side View of Half Round Scraper. Used for Internal Cylindrical Work

Marking. — The surface plate or standard is prepared by first cleaning it carefully with naphtha and then when dry by smearing it lightly with the marking compound whether it be Venetian Red or Prussian Blue. A very little usually suffices to color the plate, especially if it is well rubbed over. The work to be scraped has presumably been machined. The sharp edges and corners should be slightly beveled. If the surface of the work is clean the face of the plate can be

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carefully placed in contact with it, or, if the work is smaller than the plate, the work can be laid on the plate. With a rotary motion, and sliding it back and forth, the work is marked by the plate. After removing the plate, spots will appear on the work. They are, of course, the high points on the surface, which are removed by scraping in one direction. The surface of the work should be swept clean of dust, the surface plate rubbed over, the work marked again, and the scraping done in one direction, at right angles to previous operation. This scraping and marking may be continued until the marks from the plate increase in number and appear uniformly over the entire surface of the work. Before starting a job it is well to test the amount the work is out of full bearing with the plate. Use the thickness gage and, if there is considerable stock to be removed, first file it down.

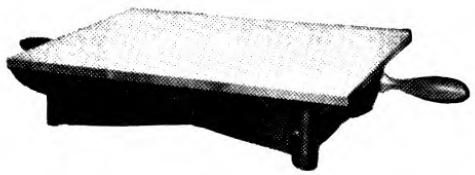


Fig. 84. A Surface Plate

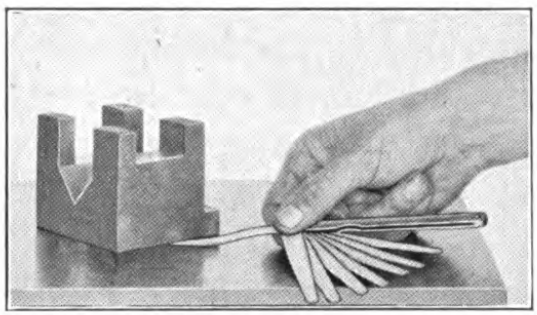


Fig. 85. Thickness Gage in use testing the Alignment between the Surface of the Work and the Surface Plate

Frosting. — This is a finish that is often put on flat scraped surfaces. It is accomplished by scraping off the high spots with very short strokes 1/4″ to 1/2″ and by changing the direction of strokes after each marking.

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CHAPTER IV

Lathe Work

Of all the machine tools the lathe is perhaps the most useful. It is used for machining cylindrical surfaces. In times past, work requiring the greatest accuracy was finished on the lathe. Now, however, due to the development of the cylindrical grinding machine, a great amount of work requiring a high degree of accuracy is first roughed out on the lathe and finished on the grinding machine. Nevertheless, the lathe will probably continue to be the most universal machine tool, Fig. 86.

Lathes can be separated into classes according to the variation in their design and the special uses to which they are put. The engine lathe may be called the all-round lathe. It is provided with both hand and power longitudinal and cross feeds. In addition, it can be used for cutting screws. The wheel lathe, turret lathe, jewelers' lathe, bench lathe, axle lathe, and the pulley lathe are names of some of the different classes.

About the first lesson for the apprentice to learn in connection with the operation of any machine is the names of the parts and the functions of the adjustments and operating handles. Instruction in operation will be hard to understand unless the operator is familiar with the names and functions of the parts. Of course, the best way to obtain this knowledge is at the machine itself, although considerable information can be obtained by studying the manufacturers' catalogs showing up-to-date machines. At this point it might be well to advise the young mechanic to form the habit of acquiring useful and up-to-date information on the tools of his trade by means of the catalogs that are issued free of charge by manufacturers.

Care of the Lathe. — Neatness about a machine is usually characteristic of a good workman. Even while the machine is in use it should be kept as neat and orderly as possible. When

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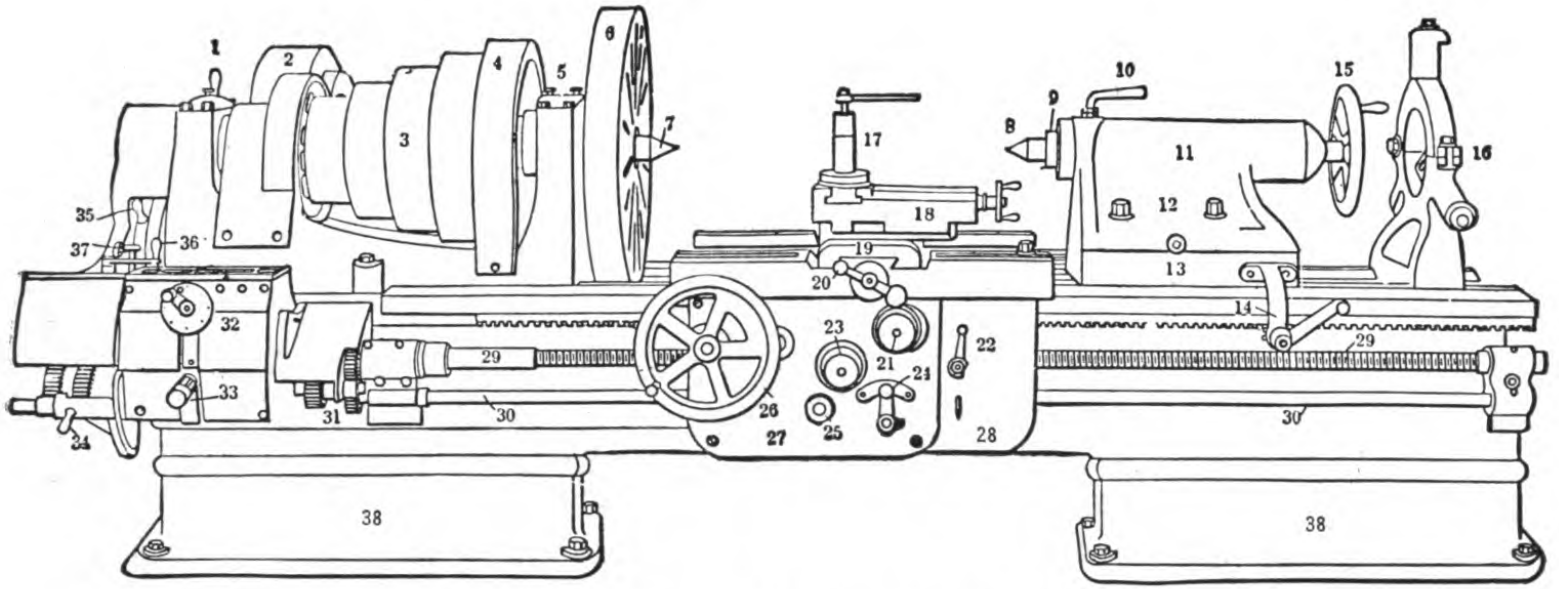


Fig. 86. Parts of an Engine Lathe

1. Rear bearing
2. Back gear case
3. Cone pulley
4. Face gear guard
5. Front bearing
6. Face plate
7. Live center
8. Dead center
9. Footstock spindle
10. Footstock spindle lock
11. Footstock
12. Footstock locking bolts
13. Footstock base
14. Arrangement for moving tailstock
15. Hand wheel for moving dead center
16. Steady rest
17. Tool post
18. Compound rest
19. Cross slide
20. Cross feed control handle
21. Power cross feed knob
22. Half nut engagement handle
23. Longitudinal power feed knob
24. Feed reverse handle
25. Gear stud
26. Longitudinal hand feed
27. Front apron
28. Rear apron
29. Lead screw
30. Power feed drive shaft
31. Change feed gears
32. Change feed box
33. Change gear handle
34. Change gear handle for compound gearing
35. Change gear handle
36. Change gear handle
37. Change gear handle
38. Bed

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the work is finished, leave the machine clean and the accessories in good order. Before starting a job be sure that everything is well oiled and in good operating condition. Be sure the oil holes are not plugged with dirt. Observe whether the belts are too loose. Report promptly anything that is out of order, to prevent more costly repairs later.

Do not put tools or work on the ways of the machine. The accuracy of the lathe depends so much on the condition of the ways that they should be protected from damage. Do not form the bad habit of using the carriage as an anvil. Wooden trays should be furnished to hold the various cutting tools and accessories. The tray may be put on the end of the machine, back of the footstock. Do not leave change gears lying about; always return them to their proper compartment. Before starting a job make sure that the centers are true. Bear in mind that the accuracy of the work begins right there — at the centers. They must be true or your work will be inaccurate.



Fig. 87. Center Gage

Testing Lathe Centers. — The headstock or "live" center may or may not be hardened; the footstock or "dead" center is usually hardened and tempered. To true or test the alignment of the centers, put a true bar between centers and with an indicator of the style shown in Fig. 89 on the tool carriage, run this indicator along the face of the bar and if it shows no variation in reading from one end of the bar to the other, the centers are in line. To check the live center for trueness an indicator can be used as in Fig. 88.

The large notch in a center gage, Fig. 87, is used to test the center angle which should be 60°. The smaller notches are

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used for testing American National or U. S. Standard (60°), and Whitworth or English Standard (55°) threading tools. The point is used primarily to test the cutting angle of inside threading tools. The four divisions, 14, 20, 24, and 32 parts of an inch, are useful in measuring the number of threads to the inch. The table on the gage is used to determine the size of tap drills for American National threads and shows in thousandths of an inch the double depth of tap thread and screw pitches in common use.

The Test Indicator. — The test indicator, three types of

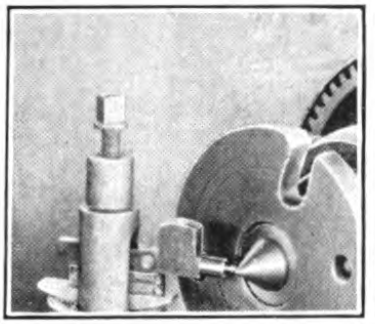


Fig. 88. Testing a lathe center with an Indicator designed especially for Lathe Work

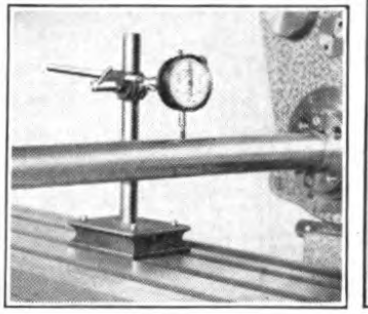


Fig. 89. Testing a long piece of work with a Dial Test Indicator

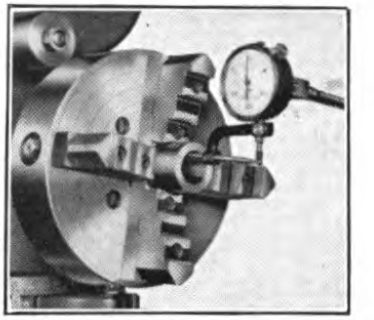


Fig. 90. Testing an inside surface with a Dial Test Indicator and Hole Attachment

which are shown in Figs. 88, 89, and 90, is used to determine the amount of eccentricity of work in motion.

To True Lathe Centers. — Before beginning to turn any piece of work requiring accuracy, always be sure that the " live " center runs true. Take the " live " center out of the headstock spindle. See that the center and hole in the spindle are clean and free from dirt. Put the center back into the spindle with the aligning marks together and tap it snugly into place with a lead maul. Start the machine and note the amount of run out. Adjust a center truing tool to the height of the axis and the angle of the center and fasten securely.

With the center turning, and using the hand cross feed, bring

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the tool up to the center and turn off a light chip; then test with the 60° notch of the center gage. Proceed thus, changing the angle of the center truing tool in the tool post, if necessary, until the angle of the center corresponds to the large notch in the gage.

The footstock center should be treated in the same way except that it should first be annealed before it is put in the headstock spindle to be turned. After it is trued to the gage it should be rehardened and drawn to a straw color before it is put back in the footstock spindle. The footstock center should be placed in the headstock and trued first and then replaced in the footstock so that the live center, after it has been trued in the headstock, need not be disturbed.

Truing Lathe Centers by Grinding. — A center grinding attachment is used, mounted on the footstock spindle or in the tool post. Be sure that the center and hole are clean so that the center fits the headstock spindle snugly. Start the machine on a fast speed (both the center and grinding wheel should turn in the same direction), and after connecting the electric cord with the circuit and starting the wheel slide, move the footstock or carriage forward to bring the grinding wheel into contact with the center. Feed the wheel toward the center with the footstock handle and traverse the wheel across the face of the center with the attachment feed handle. Take light cuts and test the center angle frequently with the center gage.

Three Ways to Align Lathe Centers for Straight Turning. — The first two of the following methods give an approximate degree of accuracy and may do for ordinary work; the third method may be considered accurate.

(1) Release the footstock clamp and move the upper section on the lower section so that the aligning points will coincide. These aligning points are at the end of the footstock under the footstock handwheel.

(2) The second method consists in sliding the footstock forward until the centers nearly touch. By turning the adjusting screws in the footstock the centers can be aligned.

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(3) After the centers have been aligned by one of the previous methods, the third and most accurate method is to mount the piece of work that is to be turned (or a piece of stock similar in length) between the centers, using a dog as in a turning operation. At the end of the work, near the headstock, make a narrow cut deep enough to true the bar, note reading on cross slide dial, withdraw tool and run carriage back to footstock end.

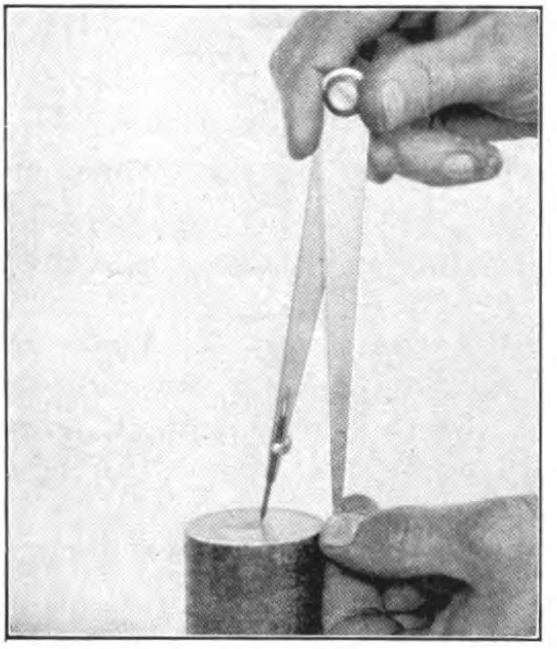


Fig. 91. Hermaphrodite Caliper in use Scribing Arcs to Locate a Center Hole

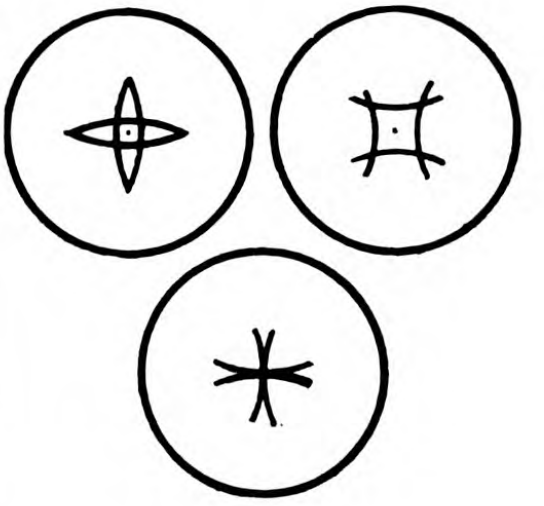


Fig. 92. Center Holes Located by Arcs Scribed by Radii of Different Lengths

Then take a second cut at footstock end to the same cross slide dial setting obtained during first cut at the headstock end. Measure the two cuts thus made with a micrometer caliper and compare the results. If the diameter measures the same at both cuts, the centers are in exact alignment. If they do not, then by means of the aligning screws in the footstock, set the "dead" center over until the diameters become equal. Do not waste time, however, in aligning with great accuracy for short or rough work.

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Center Holes. — A solid piece that is to be turned between the centers of a lathe must have center holes. They are the bearing points for the lathe centers. Center holes may be laid out by using the center head of a combination square as shown in Fig. 48, or with the hermaphrodite calipers as shown in

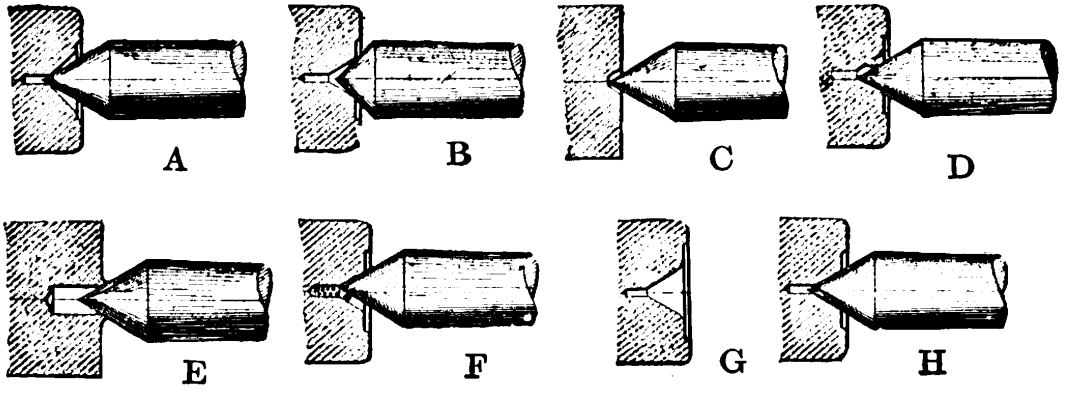


Fig. 93. A, Angle of Countersink too large; B, Angle of Center too large; C, Hole not deep enough; D, Hole upset; E, Hole not Countersunk; F, Chips in Center Hole; G, correct Center Hole as shown by fit at H

Fig. 91. Centering machines are also in more or less universal use.

With the center head and scale, any two lines scribed at random across the surface of the work will intersect at the approximate center, provided the piece of work is held snugly within the angle of the head. Lines are usually drawn at approximately right angles.

By using the hermaphrodite calipers and with a radius equal to about half the diameter of the piece, three of four arcs may be scribed as shown in Fig. 92, the center point located by eye, and prick punched.

The center holes can then be drilled and countersunk with a 60° countersink in a hand lathe. The center holes of numerous pieces are usually drilled and countersunk in a centering machine if one is available. The common angle for a center is 60°, and a finished center hole should have the same angle. In mandrels

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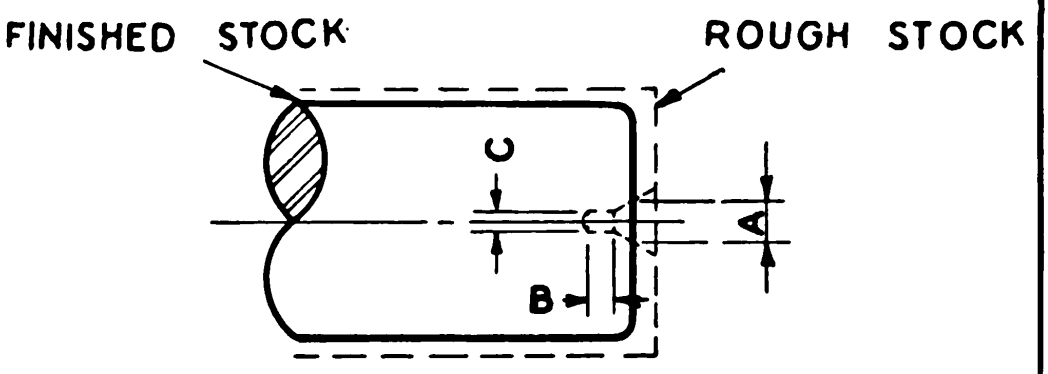
that are to be hardened, it is well to countersink the holes 59°, so that they can be easily lapped into good 60° holes after hardening. The lap may be made of copper, of the same shape as a center, and charged with emery and oil.

The center holes in the individual pieces of any lot of work should all be of the same diameter. This promotes safety and accuracy, particularly in grinding operations.

It is of the greatest importance that a center should be kept well oiled and free from dirt and chips. See Fig. 93 for examples of typical good and bad center holes.

The combined drill and countersink, Fig. 94, saves time and insures that the countersinking will be concentric with the hole. For the center holes of mandrels and milling machine arbors a combination center drill and countersink with an additional

Center Hole Sizes



Finished Size of Shaft		Center Drill	A	B	C
From	To	Diam.			
$\frac{1}{8}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{3}{64}$
$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{8}$	$\frac{5}{64}$	$\frac{1}{16}$	$\frac{3}{64}$
$\frac{1}{4}$	$\frac{11}{32}$	$\frac{1}{8}$	$\frac{3}{32}$	$\frac{1}{16}$	$\frac{3}{64}$
$\frac{3}{8}$	$\frac{17}{32}$	$\frac{13}{64}$	$\frac{1}{8}$	$\frac{5}{64}$	$\frac{1}{16}$
$\frac{9}{16}$	$\frac{25}{32}$	$\frac{15}{64}$	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{5}{64}$
$\frac{13}{16}$	$1\frac{3}{32}$	$\frac{3}{10}$	$\frac{1}{4}$	$\frac{3}{32}$	$\frac{3}{32}$
$1\frac{1}{8}$	$1\frac{15}{32}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{5}{32}$
$1\frac{1}{2}$	$1\frac{31}{32}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{32}$	$\frac{5}{32}$
2	$2\frac{31}{32}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{7}{32}$
3	$3\frac{31}{32}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{7}{32}$	$\frac{7}{32}$
4	and over	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{7}{32}$	$\frac{7}{32}$

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counterboring lip is used. The additional counterbore in the center hole is very useful in facilitating the proper mounting of work between the centers.

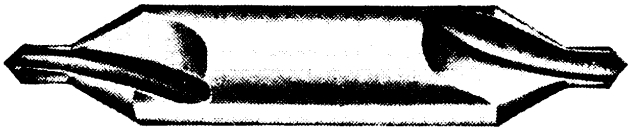


Fig. 94. Combined Drill and Countersink

There is no hard and fast rule for the size of a center hole, but it is advisable to have its diameter in reasonable ratio to the diameter of the work as indicated by the table on the preceding page. The center should be large and deep enough to furnish a good bearing and serve to prevent undue wear.

A Mandrel, Fig. 95, often miscalled an arbor, is used for work having a hole in order that the work can be held between centers

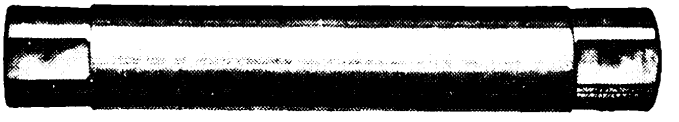


Fig. 95. Lathe Mandrel

and be machined. It may be either pressed, driven or threaded into the hole of the work. There are four kinds of mandrels: solid, expanding, built-up and gang mandrels. The more common type, the solid mandrel, is made of tool steel, hardened and ground, with a flat milled on each end to provide a seat for a driving dog screw. A solid mandrel may be 1/2 to 1 thousandth of an inch or more smaller on one end than on the other in order that the work may have a solid bearing when it is pressed on. The mandrel should always be oiled before it is pressed into the work. For accurate work the mandrel should always be tested before using.

To Straighten Work. — If after the stock has been centered in the machine and upon rotation between the centers it is perceived to be out of line, it should be straightened in the

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straightening press. Short pieces may have to be hammered into approximate alignment on an anvil.

Cutting Tools. — Lathe tools are ordinarily made of either carbon steel (tool steel), high speed steel, " stellite " or tungsten carbide. The carbon content in carbon steel ranges from about .75% to about 1.25%. When it is skillfully handled in the hardening process, it offers an extremely hard cutting edge to the work. At high speeds, however, it cannot stand the heat of work friction and it is under these circumstances that high speed steel excels. High speed steel consists of an alloy of tungsten and either molybdenum or vanadium. Although it has not the hardness of carbon steel, it maintains its hardness at speeds which may turn the tool a dull red and which would quickly ruin a carbon steel tool. " Stellite " and tungsten carbide are really not steels inasmuch as they have no iron in their composition. They cannot be forged and so are cast in shapes. These metals are almost diamond hard and are highly recommended for certain kinds of work where the cut is long and continuous. They are very brittle and so are ordinarily used in tool holders or brazed to a steel shank. Tools of these materials are usually of the round nose type; sharp pointed tools are not practical.

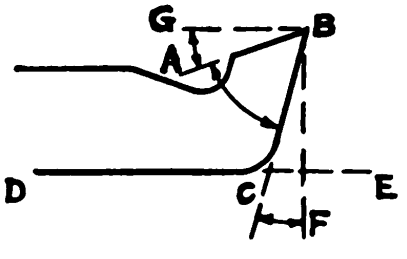


Fig. 96. Square Nose Tool

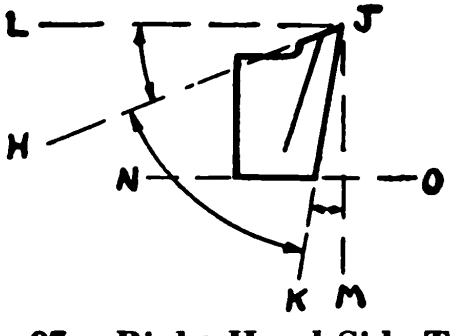


Fig. 97. Right Hand Side Tool

Rake. — As indicated in the diagram, Fig. 96, the rake of a lathe tool is the angle which the top side of the tool makes with the horizontal at the cutting point, i.e., angle *GBA*. This is called top rake to distinguish it from side rake as indicated by angle *LJ H* in the plan view of the right-hand side tool in Fig. 97.

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Cutting Angle. — In Fig. 96 the cutting angle is included between the lines *AB* and *BC*. **Clearance** is the angle formed with the vertical by the shape of the tool falling away below the cutting point, i.e., *CBF*. **Right-Hand Tools** are forged and ground to cut from right to left. **Left-Hand Tools** are forged and ground to cut from left to right.

The round nose tool, the side tool, and the diamond point tool (see Fig. 99) are the principal types used for everyday turning.

The round nose tool can be used for roughing or finishing cast iron or brass. Ordinarily it is ground with little or no rake but with a clearance of about 10° on the sides and 15° on the front end.

The Side Tool is used for facing and squaring operations. The side clearance (in Fig. 97, *KJM*) is usually about 10° and end clearance 15°; the side rake angle is *LJH*; the cutting angle is *HJK*. The point should be a full 60° angle. Side tools are forged both right- and left-hand.

The Diamond Point Tool is used for roughing or finishing cuts, particularly for finishing cuts on work of small diameter. For light work the tool can be used without much of any rake, but for substantial cuts, 15° combined front and side rake is about correct. Diamond point tools are forged both right- and left-hand.

Setting the Tool. — The cutting point of the lathe tool should be at the same height as or just above the axis of the centers.

This is usually accomplished by a provision within the tool post. On many machines, particularly those for light work, the " rise and fall " rest is used, as shown in Fig. 98.

Grinding Lathe Tools. — It should be kept in mind that the efficiency of the lathe tool depends to a great extent upon the correctness of its rake, clearance and cutting angles. Therefore care should always be exercised in sharpening a tool. Learn from an expert, if possible, and spare no pains in applying the

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instruction. Grinding the tools with a slight radius gives the best finish for straight turning. Do not give tool a sharp point. For squaring, a slight drag cut gives the best finish. Lathe tools made of carbon steel should always be ground on an abrasive wheel well flooded with water or on a wet grindstone. Tools of high speed steel, however, can be sharpened on a dry, coarse wheel. The tool gage should be used frequently to test

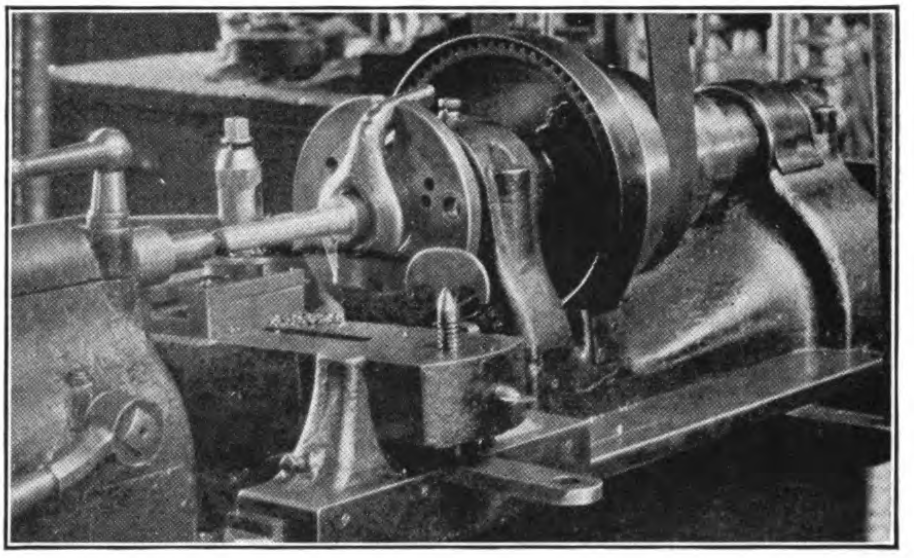


Fig. 98. Rise and Fall Rest operated by a Thumb Screw

the cutting angle. For checking angles the bevel protractor is indispensable. After sharpening a finishing tool, use a fine oil stone to remove burrs and to give the tool a good cutting edge.

Supporting Work. — When turning shafts of small diameter or when boring or threading spindles, it is often necessary to support the work while it is being machined. This is accomplished by the use of either a steady or a follower rest shown in Figs. 100 and 101.

The steady rest is bolted to the ways of the lathe and has its bearing on the work at a spot that has been previously finished. Half of the shaft is turned at a time, whereupon it is then reversed and the other half turned.

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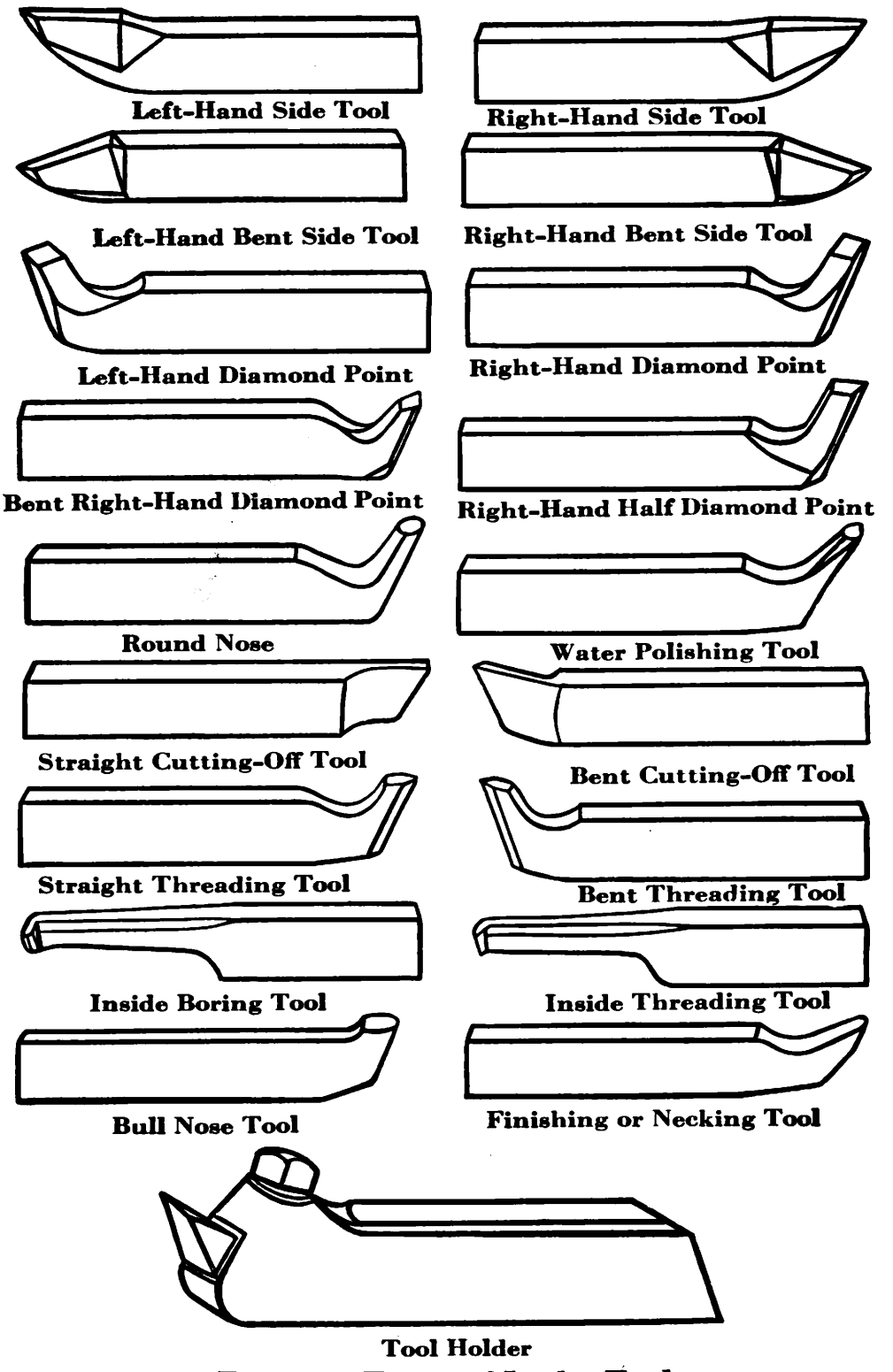


Fig. 99. Types of Lathe Tools

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The follower or traveling rest is usually bolted to the carriage of the lathe and supports the work with two jaws as it moves along with the carriage. It is used primarily when machining small work that is liable to spring if not supported. The tool should be slightly in advance of the jaws of the rest. In using the follower rest it is not necessary to reverse the work.

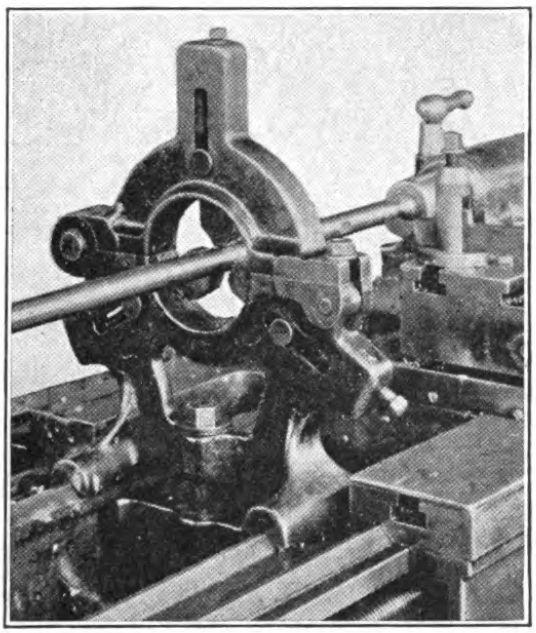


Fig. 100. Steady Rest

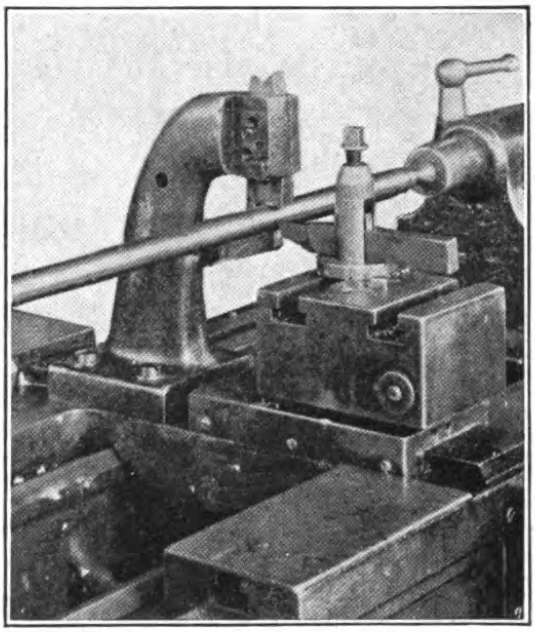


Fig. 101. Follower Rest

A lubricant should be used on the jaws to prevent any possibility of scoring the surface of the work.

Speeds and Feeds. — A resourceful workman will not be a slave to rules on the speeds of his machine. It is a good idea to find out what the tool and work will stand, and then select the most practicable and efficient feed and speed. Bear in mind that conditions will vary; the speed of yesterday need not necessarily be the speed of today.

The efficiency of a turning operation depends on the following elements: the cutting speed, which is determined by the diameter of the work; the composition of the material; the strength of the machine; the depth of cut; and feed or amount of advance made by the tool along the work per revolution of the work.

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Note the following points which must be taken into consideration with regard to turning work:

(*a*) Cutting speed in feet per minute (F.P.M.) is governed by the diameter of the work and the speed as specified by the table on pages 294 and 295; it can be measured directly by a cut meter or may be estimated.

(*b*) Depth of cut; or one half the amount that the diameter is reduced by the tool.

(*c*) Feed or amount which the tool advances per revolution of the work.

Cutting speeds and tool feeds are limited by various considerations: by the probable breaking point of the tool, by the durability of the cutting edge of the tool, by the temper, shape, or quality of the steel used in the tool, by the power in the machine drive, and by the tendency of the work to spring away from the tool point. To maintain the durability of the cutting edge be sure that the tool is sharpened so that the cutting edge will shear instead of tear off the chips in small grains. Keep the driving belts at the proper tension. If work shows a tendency to spring away from the cutting tool, take several lighter chips or support it with a follower or steady rest.

Roughing Cuts are usually deep and heavy, in fact, sometimes to a depth up to the capacity of the machine. As the strain on the tool and machine is greater, the friction of the tool and work is greater and so, in order to save the cutting edge of the tool, the speed must be slower. For any metal having a scale on its surface, set the tool for a cut of sufficient depth to get under the scale in the first cut. This will prevent the scale from dulling the tool.

Finishing Cuts are usually light and shallow, perhaps to a depth of 1/64″. The tool should have a keen cutting edge, for it is not likely to break down owing to the smaller amount of friction heat generated under these conditions.

Sometimes work is finished to grinding size. In such cases

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only a limited amount of stock is left, the amount depending on the class of work. (See Allowance for Cylindrical Grinding, page 185.)

Cutting Speed. — Cutting speed is measured in feet per minute (F.P.M.). It is the distance covered by the point of the tool on the circumference of the work, expressed in feet and during an interval of one minute. Care should be taken not to confuse revolutions of the work with circumference of the work. Two shafts of unequal diameter may be revolving at the same number of turns per minute, but the one with the larger diameter and consequently the longer circumference will deliver the greater amount of chips per revolution and the tool on the larger piece will cut faster than the tool on the smaller piece. Be sure that this is clearly understood.

For instance, the spindles of two machines are revolving at 50 revolutions a minute. The work between the centers of one machine is 4″ in diameter; the work in the other machine is 2″ in diameter. The circumference of the work in the first is $3.1416 \times 4'' = 12.56''$; the circumference of the work in the second is $3.1416 \times 2'' = 6.28''$. At the rate of 50 turns a minute of the spindles, the first tool covers $12.56'' \times 50 = 628.0''$ or 52.3 feet and the second tool cuts $6.28'' \times 50 = 314.0''$ or 26.1 feet; in other words, the cutting speed of the first is twice that of the second although the two spindles were making the same number of R.P.M.

Cutting Speed for Different Materials. — The following peripheral speed is recommended for cutting metals in the lathe when high speed steel tools are used. All speeds are based on an average turning feed. Figures indicate the Feet Per Minute periphery speed of the revolving work.

Material	Roughing Cut	Finishing Cut
Cast Iron	60	80
Machine Steel	90	125
Tool Steel	50	75
Brass	150	200
Bronze	90	100
Aluminum	200	300

See pages 294 and 295 for table of cutting speeds.

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To Find the Cutting Speed of Work. — Multiply the diameter of the work in inches by 3.1416 and multiply the product by the number of revolutions per minute the work rotates, and divide by 12. This will give the peripheral speed in feet per minute.

Example. — A piece of work 1″ in diameter, revolving 343.77 revolutions per minute, has a periphery or cutting speed of 90 ft. per minute.

$$\frac{1 \times 3.1416 \times 343.77}{12} = 90 \text{ ft. per minute.}$$

Number of Revolutions Required for a Given Cutting Speed. — Multiply the given cutting speed by 12 and divide the product by the circumference (in inches) of turned part.

Example. — Find the number of revolutions per minute for 1″ shaft for a cutting speed of 90 feet per minute.

$$\frac{90 \times 12}{3.1416 \times 1} = 343.77 \text{ R.P.M.}$$

Feed of the Tool. — There is no definite rule for obtaining the feed of a lathe tool as the class of work and conditions vary in the different shops. However, the points previously mentioned for consideration when selecting a cutting speed also apply when determining the feed of a lathe tool. There are several ways of expressing the turning feed of a lathe. The geared head lathes of today have a gear case which provides the correct feed per revolution by simply changing the gear lever. The position of the lever for respective feeds is indicated by a table on the case. Another way of expressing feeds is the number of turns of the work per inch of the tool travel. Still another way, and one which is perhaps the most common, is to state the travel of the tool per revolution of the work in thousandths of an inch. The feeds on such a lathe are usually

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indicated as .002″, .004″, .006″, etc., per revolution of the spindle.

The amount of feed to use is best obtained from experience. It is good practice to use the coarsest feed within the capacity of the lathe and consistent with the finish desired.

Screw Threads. — It may be safe to assume that the reader knows what a screw thread looks like. There are several kinds of screw threads, however, and a brief description of the more important ones will assist toward a clear understanding of the distinctions between the various kinds.

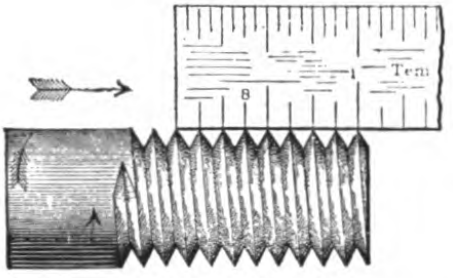


Fig. 102. Using a Scale to obtain the Number of Threads per Inch

A right-hand thread is one that has been cut in a direction such that in order to make it engage one must turn the bolt or nut in the direction followed by the hands of a clock. A left-hand thread runs in the opposite direction or counterclockwise. Most threads are right-hand threads.

An external thread appears on the outside of a piece, as in the case of a bolt. An internal thread appears on the inside of a piece, as in the case of a nut. The designation of an external thread as male, and an internal thread as female, is falling into disuse.

The threads may be cut single, double, triple or quadruple. A single thread, of course, is a thread made by a single groove; the double thread, two grooves, etc. A piece with more than one thread is referred to as multiple threaded. By inspecting the piece at the beginning of the thread it can be determined

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readily how many grooves have been cut. Most screws are single threaded.

The Pitch of a Thread is the distance from the top of one thread to the corresponding point of the next. Pitch should be expressed in fractions of an inch. For instance, a screw of

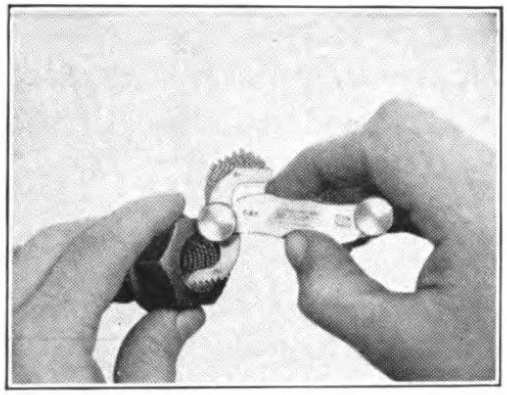


Fig. 103. Determining pitch of internal thread with Screw Pitch Gage

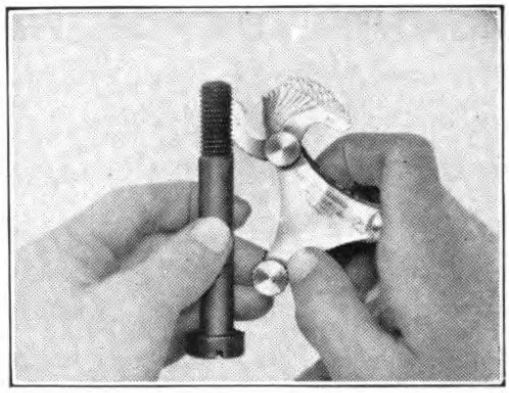


Fig. 104. Triangular type Screw Pitch Gage has wide range of blades

3/16″ pitch has threads that are 3/16″ apart from point to point.

The Lead of a Thread is the distance the screw moves in one complete turn. In the case of a single thread the lead is equal to the pitch, but in the case of double thread the lead is twice the pitch; in the case of triple thread the lead is three times the pitch.

Thread Measurements. — Two methods of measuring threads are in common use, Thread Micrometers and the Three Wire System.

Thread Micrometers are fast and convenient but subject to certain limitations. When set to read 0 with the thimble and anvil together, as is usually done, their readings over threads are always slightly distorted, the amount of distortion depending upon the helix angle of the thread being measured. The readings are not distorted when Thread Micrometers are set to a standard

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thread plug and used for measuring threads having same pitch and diameter as that plug. When so set, however, the tool does not read exactly 0 when thimble and anvil are brought together.

The Three Wire System is not as fast or as convenient as the Thread Micrometer, but is theoretically correct. However, the wires must be held very closely to theoretical size, as any error in the wires is multiplied when the thread dimensions are calculated.

Screw Thread Micrometer Caliper. — The end of the spindle of a Screw Thread Micrometer Caliper, Fig. 105, is pointed and the V in the anvil is accurately ground, and anvil

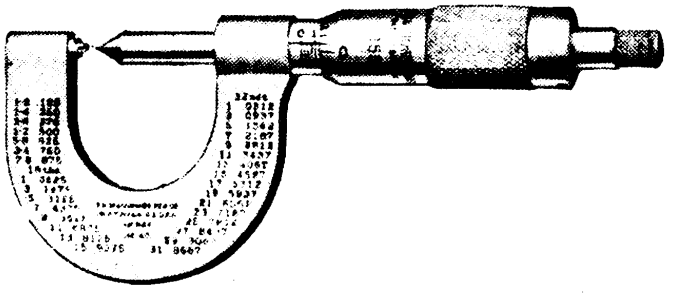


Fig. 105. Screw Thread Micrometer Caliper

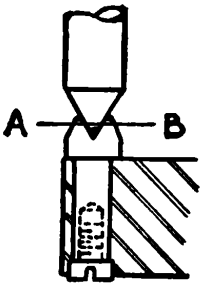


Fig. 106. Pointed Spindle End and V Anvil

is free to rotate. The end of the spindle point and bottom of the V in the anvil have allowance for clearance so they will not rest on the bottom or top of the thread to be measured. Anvil is so made that pitch diameters of very short screws with fine pitches can be measured. When set at zero, the pitch lines of spindle and anvil coincide as *AB*, Fig. 106. When the caliper is opened, the reading represents the distance between the two pitch lines or the pitch diameter. As the thread itself is measured, the actual outside diameter of piece does not enter into consideration.

The Three Wire Thread Measuring Fixture. — Fig. 107 shows an accurate means for measuring screws and external

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threads where commercial tolerances are allowable. It checks short and long taps with even numbers of flutes, and inspects external thread gages for wear.

Parts to be measured are held between the center, which is adjustable, and the V slide, also adjustable, to accommodate parts of diameters from 3/16″ to 1 3/4″. Two Micrometer Calipers, measuring from 0 to 2″, float on steel balls to insure

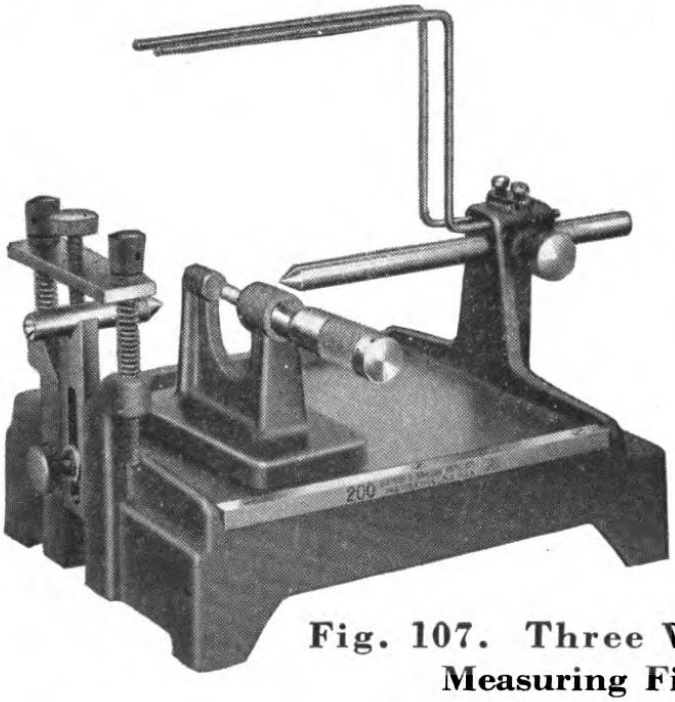


Fig. 107. Three Wire Thread Measuring Fixture

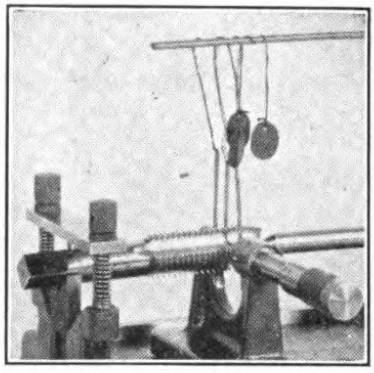


Fig. 108. Fixture in Use Measuring Thread of Tap

accurate alignment of measuring surfaces on the measuring wires.

Accurately calibrated wires are used in measuring threads with this fixture and the " Best Size " wires are the most convenient to use, as these wires are the ones that give the reading at the important working part of the thread. Larger wires can be used but smaller sizes come below the top of the thread. Too much pressure should not be applied when measuring over wires.

Figure 108 shows the Fixture in use measuring the threads of a tap. The adjustable supports are provided for holding measuring wires. On pages 284 and 285 are tables of " Best Size "

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calibrated wires and other data for use with a Three Wire Thread Measuring Fixture.

The Screw Pitch Gage. — The Screw Pitch Gages, as shown in use in Figs. 103 and 104, afford one of the easiest and most accurate methods of determining the number of threads to the inch in a screw or a nut. An ordinary scale can be used, however, as shown in Fig. 102. The rule should be placed on the top of the threads with the end coinciding with the point of one thread. The number of grooves included between the inch graduations, represents the number of threads to an inch of the screw.

Fractional Thread. — Fractional thread is the number of threads and fraction of a thread per inch that must be expressed by a fraction or mixed number as 7/8 of a thread to 1″ or 5 1/2 threads to 1″. An easy way to measure fractional threads is to put the rule across the tops of the threads and divide the number of threads that exactly line up with even inch marks, by the number of inches represented.

American National Standard Screw Threads. — During the World War there was much confusion and duplication of screw threads in machine tool and munition manufacture, and in 1918 the United States Congress provided a National Screw Thread Commission to study the problem and to report a practicable solution.

The Commission established two thread series; one called the National Fine Thread Series and the other The National Coarse Thread Series. Figure 109 shows the form and general characteristics of these threads.

The National Coarse Thread Series is recommended for general use in engineering work and machine construction where conditions are favorable for the use of bolts, screws, and other thread components where quick and easy assembly of the parts is desired, and the Fine Thread Series for general use in automotive and aircraft work and where conditions require a fine thread.

The findings of the Commission have been officially adopted

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by the War and Navy Departments and endorsed by the American Engineering Standards Committee, and, National Standard Threads are generally being adopted more and more by manufacturers and are now in general use.

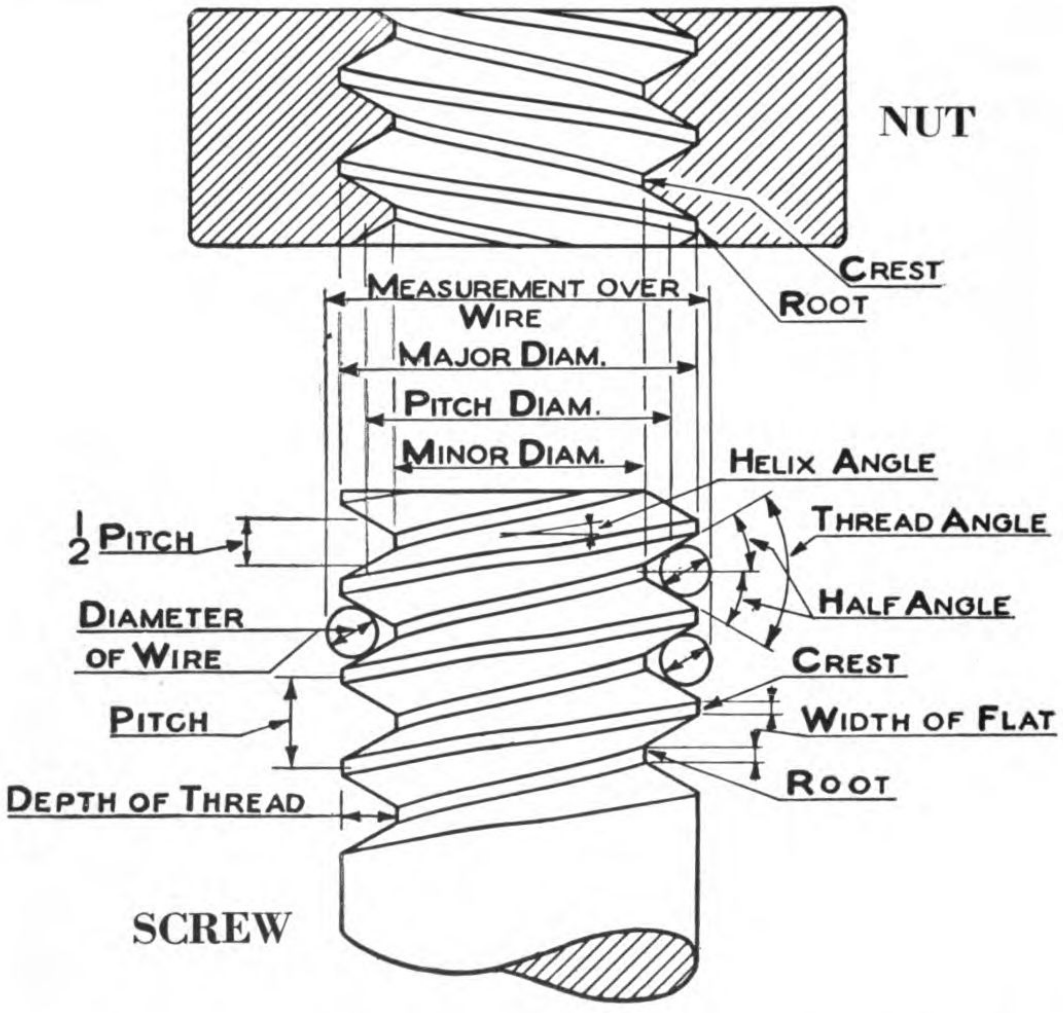


Fig. 109. American National Standard Screw Thread and Nut

These threads are made in four different classifications and tolerances:

Class 1, loose fit, is for use where threads must assemble readily and where shake or play is not objectionable.

Class 2, free fit, is for the greater bulk of screw thread work of finished and semi-finished bolts, nuts and similar parts.

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Class 3, medium fit, is for the better grade of interchangeable screw thread work.

Class 4, close fit, for work requiring a fine, snug fit. With this class, selective assembly of parts may be necessary.

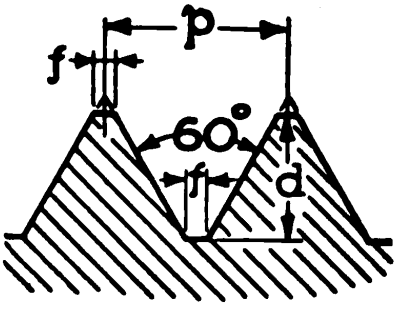


Fig. 110. The American National Standard Thread

Various Established Threads. The American National Standard Thread, Fig. 110, has many advantages. It is not easily damaged. Taps and dies made for this thread hold their size longer, and bolts and screws with this thread are stronger. (See table on pages 286 and 287.)

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}$$

$$d = \text{depth} = p \times .6495$$

$$f = \text{flat} = \frac{p}{8}.$$

The Sharp V thread, Fig. 111, is deeper than the American National Standard, but the sharp points of the teeth are easily damaged and taps and dies made for it do not hold the edges as long as taps and dies for the American National Standard Thread.

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}$$

$$d = \text{depth} = p \times .8660.$$

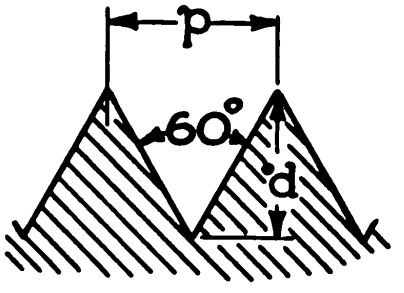


Fig. 111. The Sharp V Thread

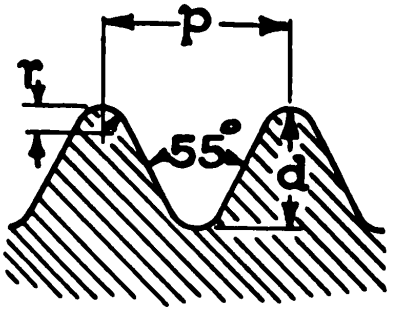


Fig. 112. The Whitworth Thread

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The Whitworth Thread, Fig. 112, is standard in England. It provides a very strong tooth but a chasing tool of a different size and shape is required for each pitch and so it is not an economical thread to cut.

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}$$
$$d = \text{depth} = p \times .64033$$
$$r = \text{radius} = p \times .1373.$$

The Brown & Sharpe 29° Worm Thread, Fig. 113, is in general use throughout America for worms. It is much deeper than the Acme thread which is also 29°. The similarity of these two threads often confuses the mechanic.

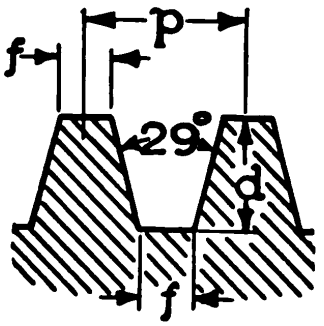


Fig. 113. The Brown & Sharpe 29° Worm Thread

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}$$
$$d = \text{depth} = p \times .6866$$
$$f = \text{flat} = p \times .335.$$

The Acme Screw Thread, Fig. 114, has about the same depth as the square thread but, because of its form, is much stronger. It is used for feed screws, lead screws and similar purposes.

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}$$
$$d = \text{depth} = \tfrac{1}{2}p + .010$$
$$f = \text{flat} = p \times .3707.$$

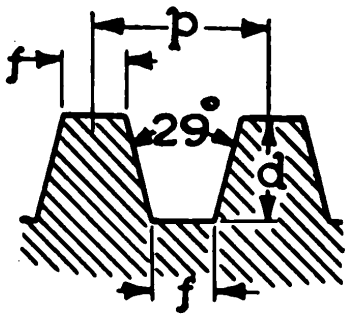


Fig. 114. The Acme Screw Thread

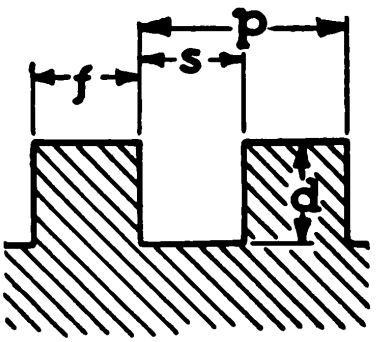


Fig. 115. The Square Thread

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In the case of the Square Thread, Fig. 115, although the depth, width of space and thread are understood to be one half the pitch, the practice is to cut the groove slightly wider and deeper.

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}$$
$$d = \text{depth} = \tfrac{1}{2}\, p$$
$$f = \text{flat} = \tfrac{1}{2}\, p$$
$$s = \text{width of space} = \tfrac{1}{2}\, p.$$

By reference to the foregoing diagrams, the difference between the shapes of the various threads will readily appear. The tables on pages 286 to 290 give the diameters and numbers of threads per inch of the various standard threads.

Thread Cutting on an Engine Lathe. — As we know, the spindle of the lathe rotates the work that is to be threaded. By means of a train of gears, the spindle turns the lead screw. The lead screw, while in mesh with the split nut located behind the apron of the carriage, moves the carriage along the bed at a fixed and constant speed. The speed with which the carriage moves in relation to the revolutions of the work, naturally determines the lead of the thread. This relation between work speed and carriage travel is directly controlled by the number of teeth in the gears selected for the gear train.

Every screw cutting lathe is furnished with a set of gears with different numbers of teeth. These gears determine the range of threads that can be cut on the lathe.

A number of the more common threads can be cut by using simple gearing, Fig. 116, whereas compound gearing, Fig. 117, is necessary when simple gearing will not serve.

In either case, the gearing is figured assuming that the spindle stud has the same speed as the spindle. If the speed is not the same, account must be taken of the difference in speed. This is done by using an " assumed " number of threads for the lead screw, rather than the actual number, in order to compensate

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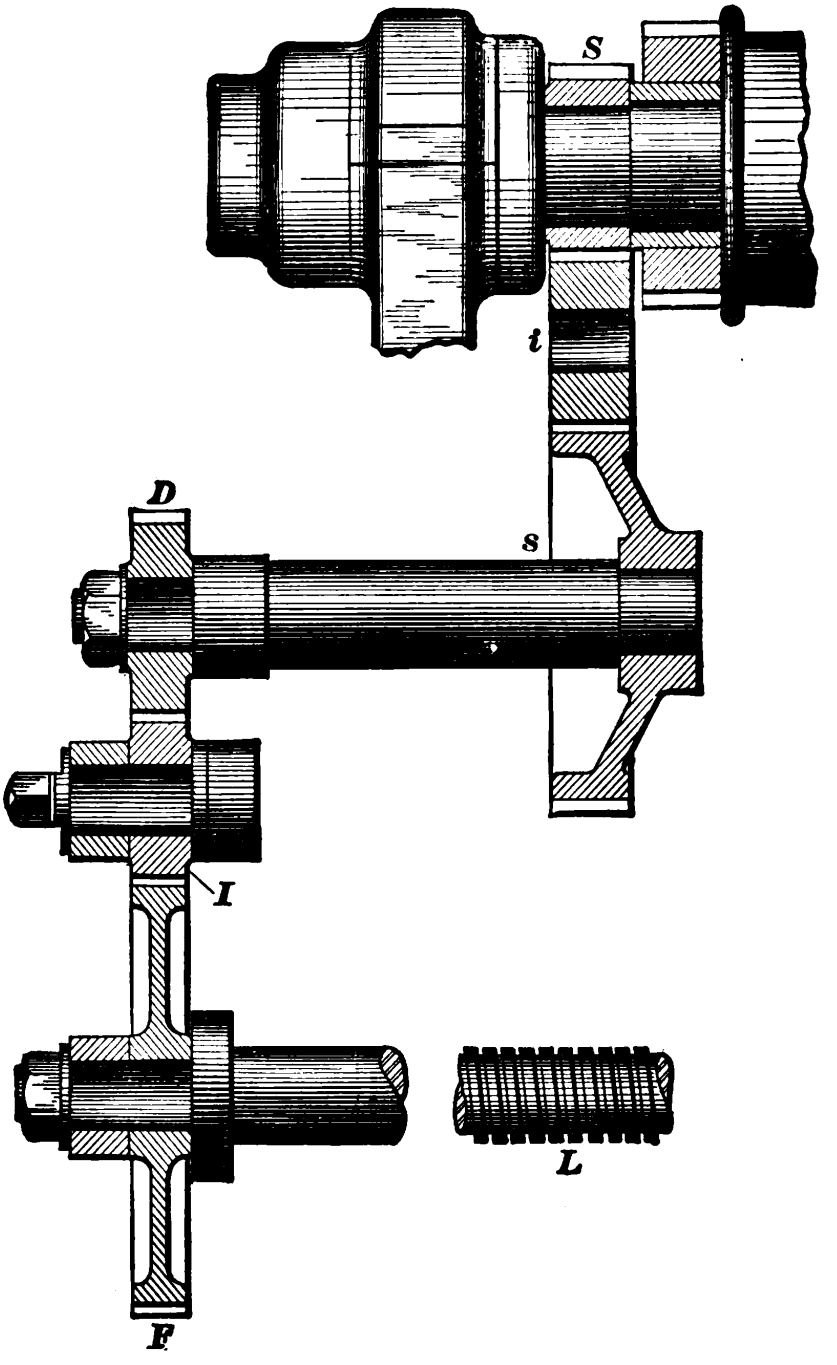


Fig. 116. Simple Gear Train

On many lathes a change gear is not put directly on the spindle but on a stud as shown by D, on stud s. Stud s is driven through the intermediate gear i by the gear S on the spindle. Change gear D is a driving gear that drives the lead screw L by means of the lead screw change gear F, through the intermediate gear I. Gear D is sometimes called the spindle stud change gear.

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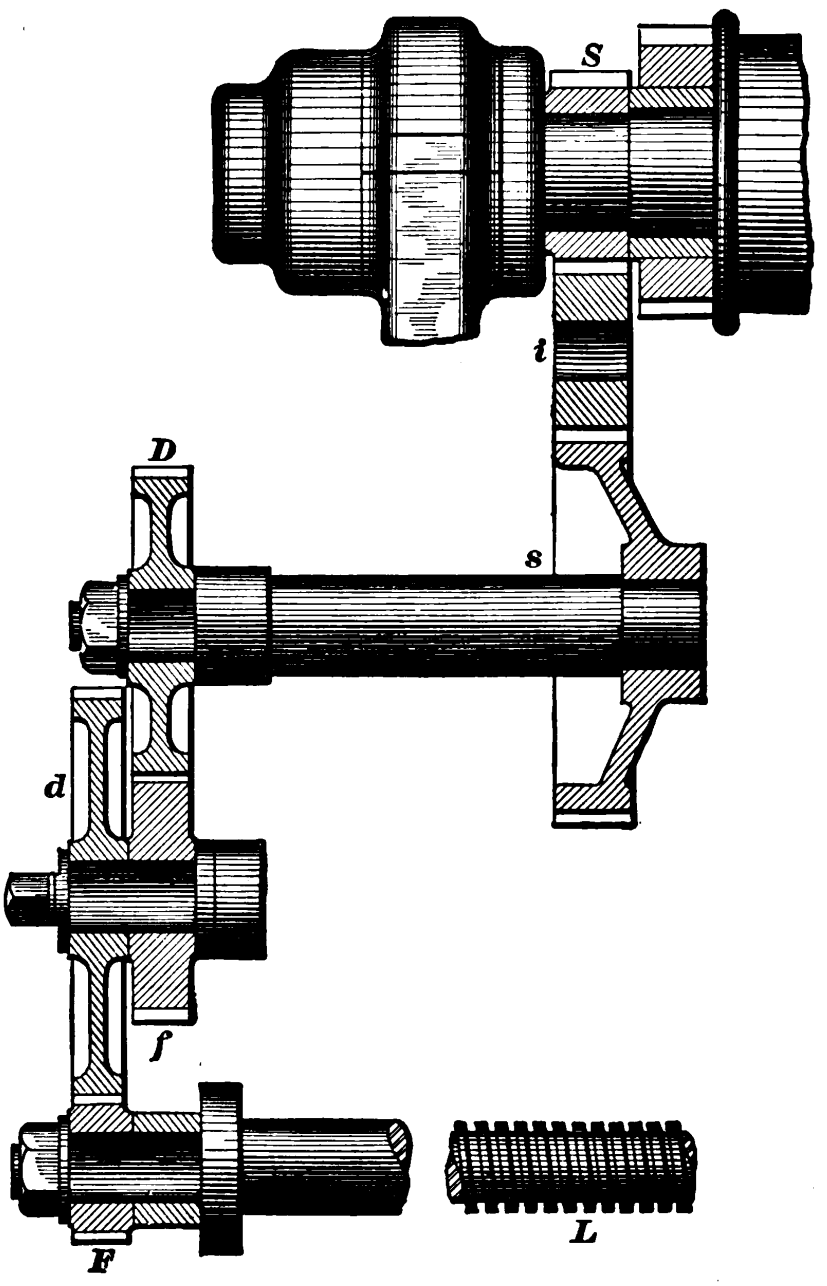


Fig. 117. Compound Gear Train

In compound gearing two stud change gears, d and f, are used to increase the range of threads per inch that can be cut with any set of change gears. D is the spindle change gear driving the stud change gear f. The other stud change gear, d, is also a driver that drives the lead screw L by means of the lead screw change gear F. Note that D is shown on the spindle stud s, which is driven by gear S on the spindle through the intermediate gear i.

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for the speed ratio between spindle and spindle stud. In referring to the change gear which goes on either the spindle or spindle stud, this gear will be called the spindle gear.

Selection of Change Gears for Simple Gearing. — A train of simple gearing is illustrated in Fig. 116. In this train, gears *D* and *F* are change gears and the number of teeth in these gears determines the thread the lathe will cut. To obtain the proper gears for a desired number of threads, the following formula may be used:

$$\frac{\text{Number of Threads in Screw to be Cut}}{\text{Number of Threads in Lead Screw}} = \frac{\text{Lead Screw Gear}}{\text{Spindle Gear}}.$$

For example, to find the gears for cutting a screw of 6 threads per inch on a lathe whose lead screw has 5 threads per inch, substitute in the above formula 6 for "Number of Threads in Screw to be Cut" and 5 for "Number of Threads in Lead Screw." We have then the ratio $\frac{6}{5}$. There are, of course, no change gears available having 6 or 5 teeth, and consequently it is necessary to multiply both the numerator and denominator by a common figure to obtain such numbers as will correspond to the numbers of teeth among the available gears. Multiplying by 6 we have

$$\frac{6}{5} \times \frac{6}{6} = \frac{36}{30}.$$

In the previous formula the numerator is the gear for the lead screw and the denominator the gear for the spindle. By putting the 36 tooth gear on the lead screw and the 30 tooth gear on the spindle (or spindle stud) the lathe is geared for the proper feed to cut 6 threads to the inch.

Selection of Change Gears for Compound Gearing. — Figure 117 illustrates a train of compound gearing. The change gears are *D*, *f*, *d*, and *F*. Changing the number of teeth and making various combinations of these four gears will give

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various threads. To obtain the gears for a desired thread this formula may be used:

$$\frac{\text{Number of Threads in Screw to be Cut}}{\text{Number of Threads in Lead Screw}} = \frac{\text{Lead Screw Gear}}{\text{Spindle Gear}} \times \frac{\text{Driven Gear on Stud}}{\text{Driving Gear on Stud}}.$$

First compute as in simple gearing and divide the ratio obtained into any two ratios. Multiply these ratios by a common figure to obtain such numbers as will represent available gears.

For example, to cut a screw having 22 threads to the inch, the lead screw having 6 threads to the inch, substitute in the first expression in the formula, 22 for " Number of Threads in Screw to be Cut " and 6 for the " Number of Threads in Lead Screw " and the ratio $\frac{22}{6}$ will be obtained. Divide this ratio into two ratios, as $\frac{11}{6} \times \frac{2}{1}$. Multiply the terms in both ratios so that the number found will be the same as the teeth of gears available. Increasing the terms of the first ratio by a common multiplier as 5, gives $\frac{11}{6} \times \frac{5}{5} = \frac{55}{30}$. Multiplying the second ratio by 20, gives $\frac{2}{1} \times \frac{20}{20} = \frac{40}{20}$. Thus the required gears for the ratio $\frac{22}{6}$ will be 55 for the Lead Screw Gear; 30 for the Spindle Gear; 40 for the Driven Gear on Stud (Inner Gear); and 20 for the Driving Gear on Stud (Outer Gear).

Screw cutting lathes are furnished with tables showing gears to use for various threads to be cut and, also, the formula to use in calculating the gears.

Threading Tools are forming tools inasmuch as they shape the threads as the work turns in contact with the tool and the carriage feeds along the work. Threading tools are hardened and tempered. The front clearance should be about 15°. In grinding, the top face is ground and the front faces are sharpened to fit the 60° tool notch of the center gage, Fig. 87.

Thread Cutting. — After the work has been turned to the correct diameter and chamfered on the tailstock end to the

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depth of the thread to be cut, the threading tool should be held in the tool post. A two inch projection of the tool from the post should give enough rigidity. Put the point of the tool at the height of the " dead " center and hold the center gage (in an attachment if available) as in Fig. 118. Using the cross feed, and tapping the tool to the right or left, bring the tool up to fit the notch in the gage. When the adjustment is satisfactory and indicates that the tool fits the gage, clamp the tool securely in the tool post.

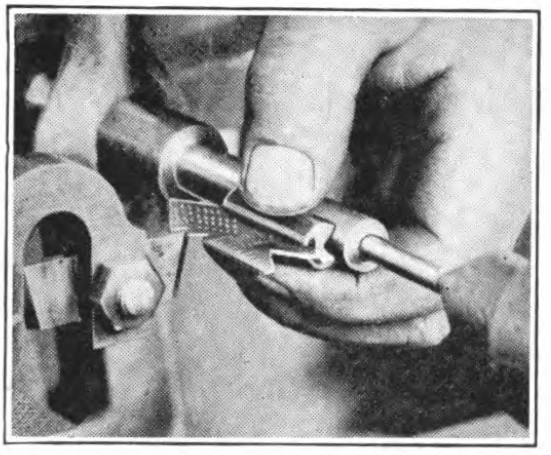


Fig. 118. Using a Center Gage to Set a Thread Tool

Before beginning the thread, cut a groove to start the tool and then take a very light cut from right to left. On the first cut, stop the lathe before the tool reaches the end of the thread and finish the thread by pulling the belt by hand. Check carefully the number of threads before proceeding with the work. If it is impossible to ease off the thread at the end of cut because of a shoulder, the work should be prepared as follows, before placing in the lathe. At a point that is to be the end of the thread and where an abrupt stop must be made, drill a hole the diameter of, and to the depth of the required thread. When cutting into a hole, the lathe should be stopped and the thread finished as previously mentioned. Often a groove somewhat wider than the pitch and of equal depth is turned into the shaft at the end of the thread and the tool runs out into this.

Keep in mind that the proper speed for thread cutting should be one half to two thirds the speed used in turning. Keep the point of the tool sharp, particularly when taking the finishing chip. Use an oil stone on the tool point for the last cut in order to improve the finish.

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In threading taper work, such as pipe taps, it is advisable to use the taper turning attachment. Be careful in setting the tool to have it at right angles with the axis of the work instead of at right angles with the taper surface.

Cutting Left-Hand Threads. — In cutting left-hand threads the gears are placed as in cutting right-hand threads. The direction of rotation of the lead screw must be reversed by a reversing gear in the train or by using an extra idler.

Lubricant for Thread Cutting. — In cutting threads on steel, wrought or malleable iron, use a good grade of lard oil. The use of a thread brush and a shallow oil pan placed on the lathe carriage directly under the thread tool will be found very convenient. On the return travel of the lathe carriage, when the thread tool is withdrawn, clean the threads and thread tool of all chips and then flood the work with the lubricating oil. The excess oil will drain into the pan which is usually provided with a strainer to separate the chips.

Tapers and Taper Turning. — Tapers are denoted by so many inches or parts of an inch per foot; as 1″ per foot or 3/8″ per foot. They are sometimes indicated by degrees and minutes; as 6° 42′ or 2° 35′. There are certain well known tapers in use which have become recognized as standard for machines on which they are used. The Milling Machine Standard Taper, 3 1/2″ per foot, is generally used by manufacturers of milling machines and associated products. The Brown & Sharpe Taper, which is approximately 1/2″ per foot, except No. 10 which is .5161″ per foot is commonly used on collets, shanks of arbors and end mills. The Morse Taper, approximately 5/8″ per foot, is in use on shanks of drills, sockets, end mills, holes in drill press spindles and lathe spindles. The taper of pipe ends is 3/4″ per foot and is considered standard in some plants.

Methods in Use to Turn Tapers. — There are three ways in common use to turn a taper:

(1) Setting the " dead " center out of line with the " live " center.

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(2) By using a taper turning attachment.

(3) By using a compound rest.

The first method can be used for outside turning only. The two other methods are applicable to turning and boring. The tool must be kept on a level with the centers to maintain the taper. If the correct taper is provided with tool on center, raising or lowering the tool will change the taper.

Tapers can be turned, also, by working with a special taper turning lathe on which the headstock and footstock can be set at an angle to the line of tool feed movement although this is not a common practice.

How to Calculate the Set-Over of the Footstock. — First take 1/2 the taper per foot and divide it by 12 to change it to taper per inch. Multiply this result by the total length of the work or mandrel in terms of inches. (*Note*: We say work or *mandrel* because it is the distance between centers that counts. The work can be much shorter than that distance. The mandrel will be equal, however, to the distance between centers.) Thus, with the Brown & Sharpe Taper which is approximately 1/2″ per foot (page 296), we obtain the set-over for the footstock for work which requires a center distance of 18″, as follows: We take first 1/2 of the taper per foot which is 1/4″. Then we divide this result by 12 to convert it to taper per inch; 1/4″ × 1/12″ = 1/48″. We then multiply the result by the total length of the work, 18″; 1/48″ × 18″ = 3/8″ or .375″. Thus the set-over for the footstock is 3/8″ or .375″.

To Set Over the Footstock. — (See table of tapers on page 299.) Suppose we wish to set over the footstock the amount calculated above; we loosen the clamping bolts on the footstock and by using the adjusting screw and observing the zero lines in the rear, we move the upper part of the footstock until the top zero line is .375″ from the bottom zero line. Use a pair of dividers set at .375″ to check this adjustment.

When the Length and Diameters Are Known, but Not the Taper per Foot, to Find the Set-Over. — Suppose

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the length is 18″; the larger diameter 8″, the smaller one 7″, and the length of the tapered surface 12″. Use this formula:

$$\frac{\text{Larger diameter} - \text{smaller diameter}}{2} \times \frac{\text{Total Length}}{\text{Length of part}} = \text{Set-over}$$

Thus:

$$\frac{8'' - 7''}{2} \times \frac{18''}{12''} \quad \text{or} \quad 1/2'' \times 3/2'' = 3/4'' = .750''.$$

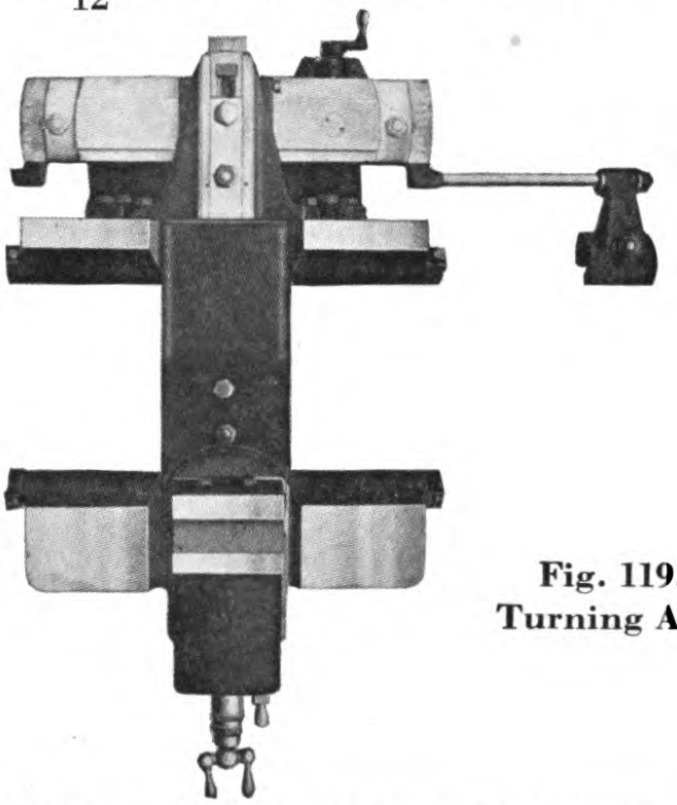


Fig. 119. Taper Turning Attachment

Set-Over from a Sample Piece or Pattern. — It may happen that a piece with the exact taper desired is available. In such a case, mount the piece between the centers and with a test indicator in the tool post, run the contact point of the indicator along the tapered surface and adjust the screws in the footstock until the set-over is correct for the sample piece, as shown by the absence of variation as the indicator is moved along the taper. Then clamp the footstock and replace the sample piece with the work to be tapered.

The Taper Turning Attachment. — The taper turning attachment can be applied readily to a lathe to turn either out-

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side or inside tapers, and with this device there is no need of setting over the footstock. The taper required can be obtained by setting the guide bar at an angle corresponding to the taper desired.

The Compound Rest. — Very abrupt tapers are usually turned with the compound rest. It is simply an extra slide for

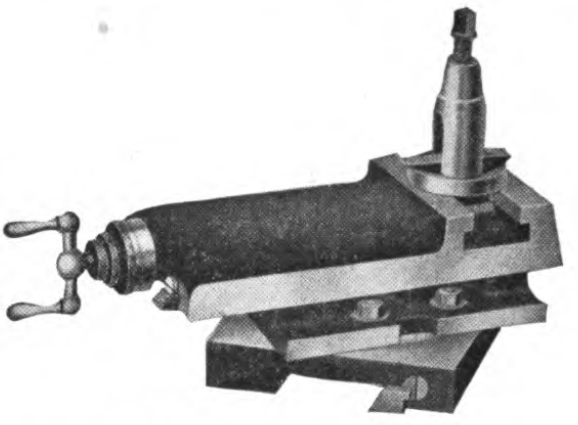


Fig. 120. Compound Rest

carrying the tool block and this extra slide is mounted in the usual position of the tool on the saddle. A circular base is provided for this extra slide so that the slide can be rotated at any angle in a horizontal plane. The base is graduated to degrees and the extra slide is set at an angle so that the direction of the movement of the tool will correspond to the desired taper.

Testing the Accuracy of a Taper. — Test the accuracy of a piece of tapered work as you go along by trying it in a gage that represents the desired taper. When the work appears to fit solidly in the gage, with no rattle or shake, test its bearing by applying a very little Prussian Blue, after the manner in use on surface plates. If the contact spots are distributed evenly over the surface of the taper it may be considered a good fit. The work can then be put between the centers again and finished off with a very fine file.

Working to an Angle is one of the most perplexing problems that confronts an apprentice, and some journeymen as well. A

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mistake may arise as to the size of an angle from not knowing where it begins or ends. The measurement of an angle may be wrong because the measuring instrument or protractor indicates one angle when another is wanted. Working to an angle with a machine may develop the disturbing surprise that the workman has chosen a wrong setting for the machine, because he either did not understand from what line the figuring of the angle began, or because the machine must be set at an angle different from the one that is called for on the drawing.

It requires careful study to learn how to work to an angle, and to many workmen it is not an easy task.

An Angle, as commonly defined, is the space between two straight lines that meet in a common point. Another definition is that an angle is the difference in direction between two lines that either meet or would meet if sufficiently prolonged. In

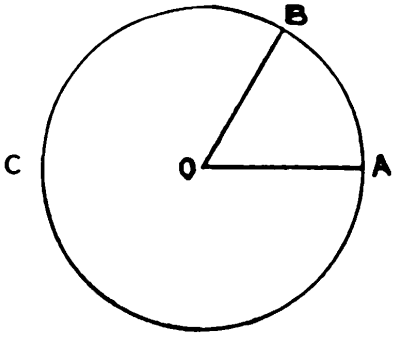


Fig. 121

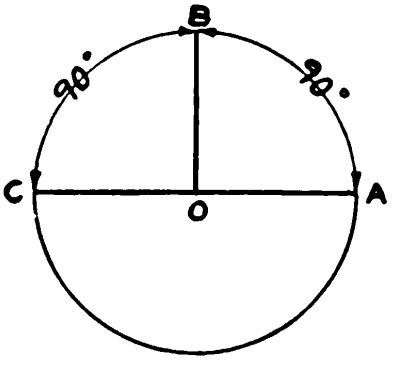


Fig. 122

Fig. 121, the difference in direction between the lines *AO* and *BO* is the angle *AOB*. *AO* and *BO* are the *sides*, and *O* is the *vertex* of the angle.

The circumference of a circle drawn about the vertex as a center, and through the sides of an angle, can be used to measure the angle. Thus, the circumference *ABC* is drawn about the vertex *O*, and the angle *AOB* is measured by the arc *AB*.

In order to measure angles, the circumference is divided into 360 parts; each of these parts is called a *degree* (°). A degree is

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divided into 60 parts called minutes (′); and a minute is divided into 60 parts called seconds (″).

One kind of a tool for measuring angles, called a bevel protractor, is seen in Figs. 51 and 123.

The dial of this tool is graduated into degrees over the entire circle. It reads by means of a Vernier, Fig. 53, to 5 minutes or 1/12 of a degree and provides an accurate means of taking angular measurements and establishing angles.

A Right Angle is measured by a quarter of a circumference of a circle, which is equal to 90° when the vertex is at the center of

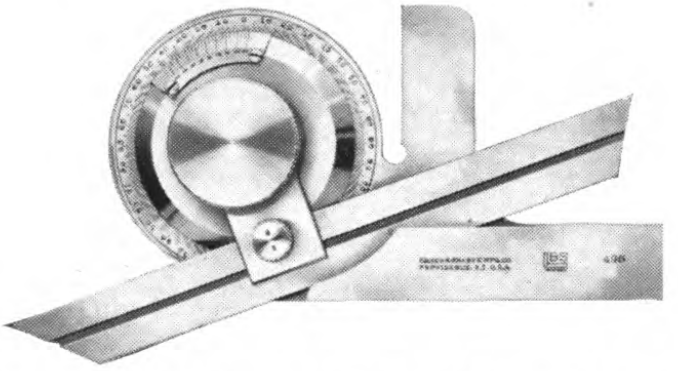


Fig. 123. Bevel Protractor for Measuring Angles

a circle. In Fig. 122, *AOB* and *BOC* are right angles. A line *BO* is at right angles with a straight line *AC*, which is also the diameter of a circle, when the angles on each side of *BO* are equal.

A square is a familiar example of a right angle.

The half circumference *ABC*, which equals 180°, measures two right angles, and the side *AO* of one right angle and the side *CO* of the other right angle form one and the same straight line, *AOC*. An angle of 180°, which is known as a straight angle in geometry, is not usually regarded as an angle, in machine work.

Various Angles and Their Uses. — Two uses of angles are common in machine work, one to measure a circular movement, the other to measure a difference in direction. Angles can be studied from different points of view, according to the use that is to be made of them. In general they may be regarded as being

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formed with a radius *OB*, Figs. 124 and 125, moving about *O*, the origin of angles being at *A*. The radius, as shown in Fig. 124, has reached *B*, and formed an angle, *AOB*, of 135°; and in Fig. 125, the radius has passed *C* and reached *B*, the arc *ACB* being 315°.

An angle can be measured in two directions: thus, in Fig. 125, the angle *AOB* can be measured with the arc *ACB*, which is 315°, and also with the arc *ADB*, which is only 45°.

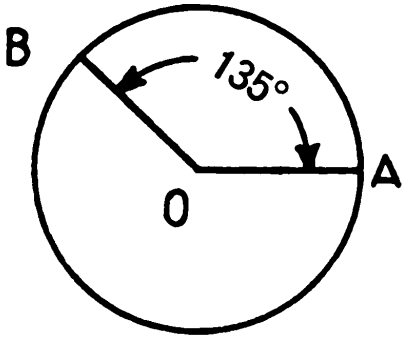


Fig. 124

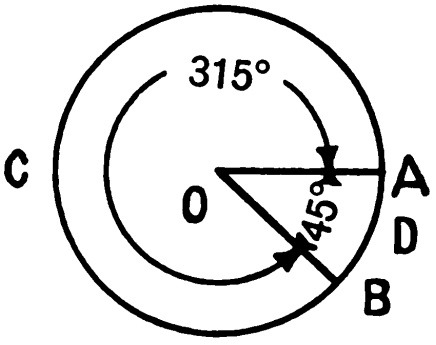


Fig. 125

Subtract the degrees an angle measures one way from 360°, and the remainder is the number of degrees it measures the other way. Thus, *AOB*, Fig. 125, is 315° measured with the arc *ACB*; subtracting 315° from 360°, the remainder, 45°, is the angle *AOB* when measured with the arc *ADB*. Either way of measuring indicates simply the difference in direction; but, in working to an angle, the direction that is wanted must be clearly understood.

When angles are used to measure rotation, if a piece has rotated through a certain angle, it is not always convenient to use the other angle to express the rotation. Thus in Fig. 125, 315° expresses the *movement* of *OB* through *C* around to *A*, while it might be said that the *direction* of *OB* is 45° from *OA*. The radius *OB* can continue to rotate through any number of degrees; and when it has rotated through 360° it again coincides with the radius *OA*. The rotation of a shaft can be expressed in degrees; 90° are equal to a quarter of a revolution and 360° to one revolution.

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The consideration that one angle is the difference between 360° and another angle, seldom comes up in machine work, but it is not uncommon to have an association of two angles that together equal 180°.

The Supplement of an Angle. — In Fig. 126, the straight line *BO* meets the straight line *AD* at *O*, and the angle *AOB* added to *BOD* equals 180°. Subtract one angle from 180° and the

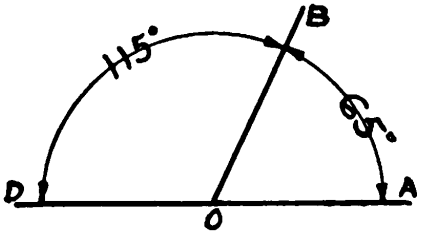


Fig. 126

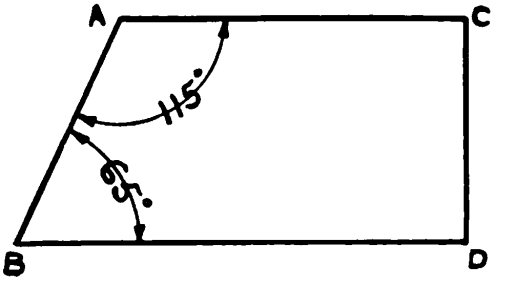


Fig. 127

remainder is equal to the number of degrees in the other angle. The difference between 180° and any angle is called the *supplement* of the angle. When the sum of two angles equals 180°, each angle is the supplement of the other, as in Fig. 126.

An *acute* angle is less than 90°, as *AOB*. An *obtuse* angle is greater than 90°, as *BOD*.

Two supplementary angles whose sum is equal to 180° are also shown in Fig. 127. If the piece *ACDB* has the side *AC* parallel to the side *BD*, the sum of the angles *CAB* and *ABD* will be equal to 180°, and if the side *AB* inclines so as to make the angle *ABD* acute, the angle *BAC* will be obtuse. The angle *BAC* is 115°, which subtracted from 180° leaves 65° as the angle *ABD*; and, as the sides *AC* and *BD* are parallel, the sum of these two angles equals 180°.

It is important to understand Figs. 126 and 127. Unless the relation of an angle to its supplement is clearly understood, it is almost useless to attempt to work with angles.

Angles Associated with 90°. — Two or more angles may be associated with 90°. Sometimes the sum of the angles equals 90°; at other times it is the difference between two angles that is

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equal to 90°. A drawing may call for one angle and the machine have to be set to the other. This association of two angles with 90° leads to many of the mistakes connected with angles.

Be sure the relationship of the angle with the setting as well as any relationship with 90° is thoroughly understood before attempting to work in angles.

Complement of an Angle. — The angle *AOC*, Fig. 128, is a right angle, and the sum of the angles *AOB* and *BOC* is equal to a right angle. The difference between any angle and a right angle

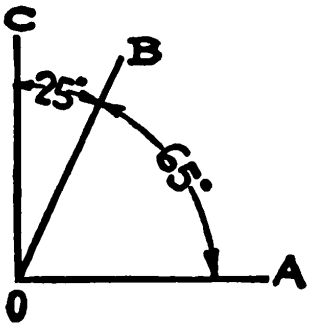


Fig. 128

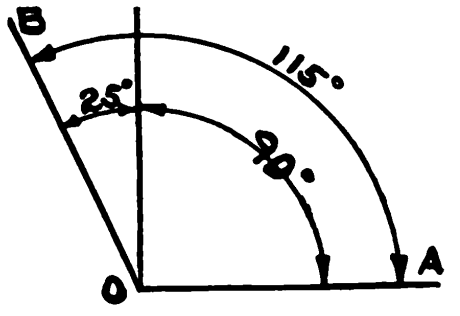


Fig. 129

is called the *complement* of that angle. Thus, in Fig. 128, 25° is the difference between 65° and 90°, and 25° is the complement of 65°. If the sum of two angles is equal to 90°, each angle is the complement of the other; 65° is the complement of 25°.

In Fig. 129, the angle *AOB* is greater than a right angle, being 115°, or equal to 25° added to 90°.

TABLE FOR DIVIDING CIRCLES OR LAYING OUT GEOMETRICAL FIGURES

No. of Sides	Included Angle	Angles at Center of Circles	Angles for Sides of Figures
3	120°	30°	30°
4	90°	45°	45°
5	72°	18°—54°	36°—72°
6	60°	30°	30°
8	45°	45°	22° 30′
10	36°	54°—18°	18°—54°
12	30°	60°	15°—45°
14	25° 43′	64° 17′—38° 34′—12° 51′	12° 51′—38° 34′—64° 17′
16	22° 30′	67° 30′—45°	11° 15′—33° 45′
18	20°	70°—50°—30°—10°	10°—30°—50°—70°
20	18°	72°—54°	9°—27°—45°
24	15°	75°—60°—45°	7° 30′—22° 30′—37° 30′

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TAPERS PER FOOT AND CORRESPONDING ANGLES

Taper per Foot	Included Angle	Angle with Center Line	Taper per Foot	Included Angle	Angle with Center Line
1-8″	0°—36′	0°—18′	1″	4°—46′	2°—23′
1-4	1°—12′	0°—36′	1 1-2	7°—09′	3°—35′
5-16	1°—30′	0°—45′	1 3-4	8°—20′	4°—10°
3-8	1°—47′	0°—54′	2	9°—31′	4°—46′
7-16	2°—05′	1°—02′	2 1-2	11°—54′	5°—57′
1-2	2°—23′	1°—12′	3	14°—15′	7°—08°
3-4	3°—35′	1°—47′	3 1-2	16°—36′	8°—18′
15-16	4°—28′	2°—14′	4	18°—55′	9°—28′

Draftsmen's Protractor. — This instrument, Fig. 130, can be set quickly to any angle; used either side up and on either of the two outside edges of the frame. It can be used to advantage in dividing a circle, laying out angles and tapers, and transferring angles on either side of a line, without resetting.

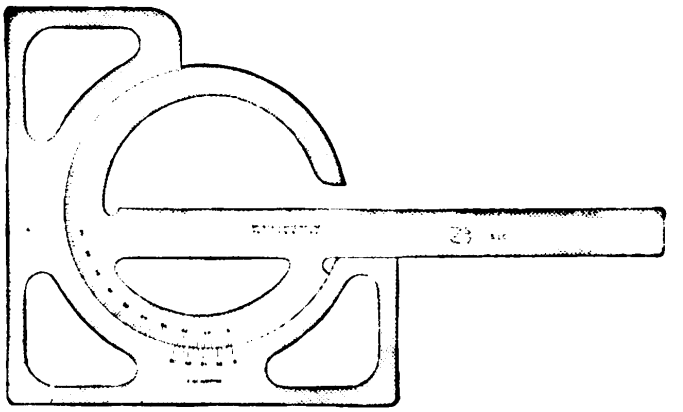


Fig. 130. Draftsmen's Protractor

The Vernier reads to five minutes.

This protractor forms a convenient extension of a T square and frequently takes the place of 45° and 60° triangles.

The groove and tongue of the Protractor should occasionally be wiped with an oiled cloth in order that the surfaces may work freely against each other.

Uses of a Bevel Protractor. — A few of the uses of the Bevel Protractor, Figs. 51 and 123, are illustrated in Figs. 49, 131, 132, 133 and 134.

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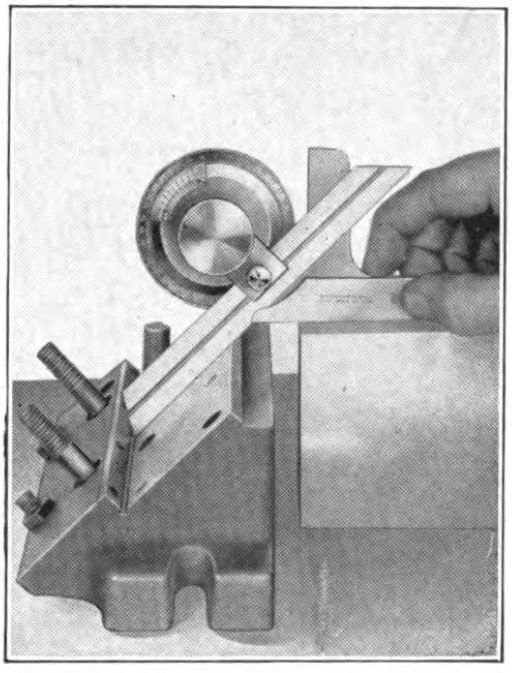


Fig. 131. Bevel Protractor used with knee to measure fixture angle

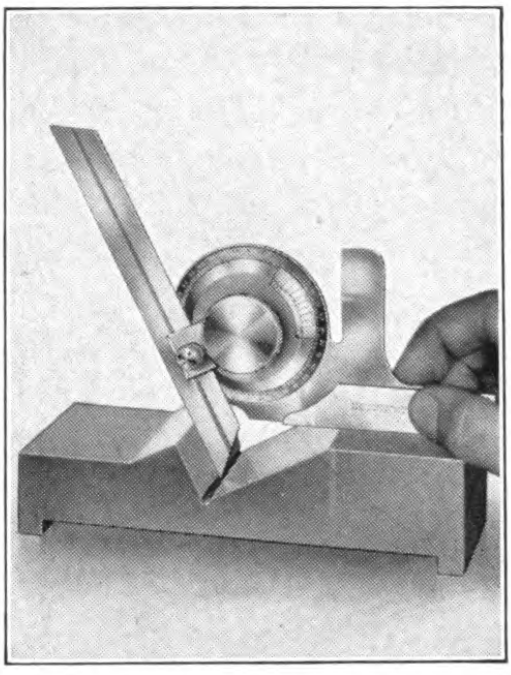


Fig. 132. A Bevel Protractor determines angle and its relationship to other surfaces

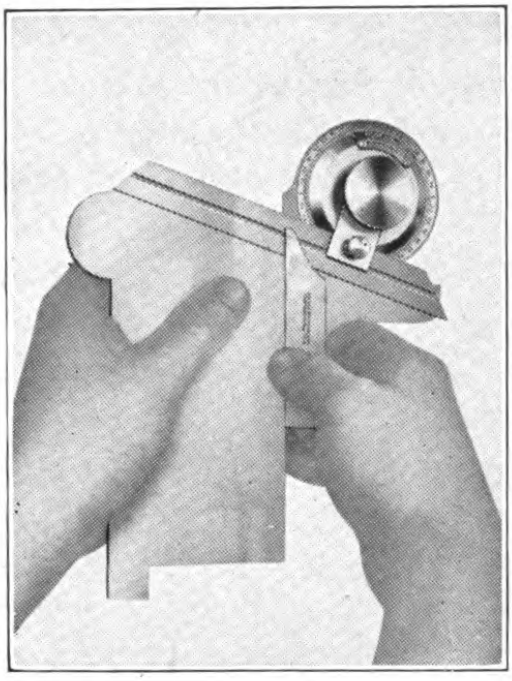


Fig. 133. Checking Angular Surfaces on Special Gage

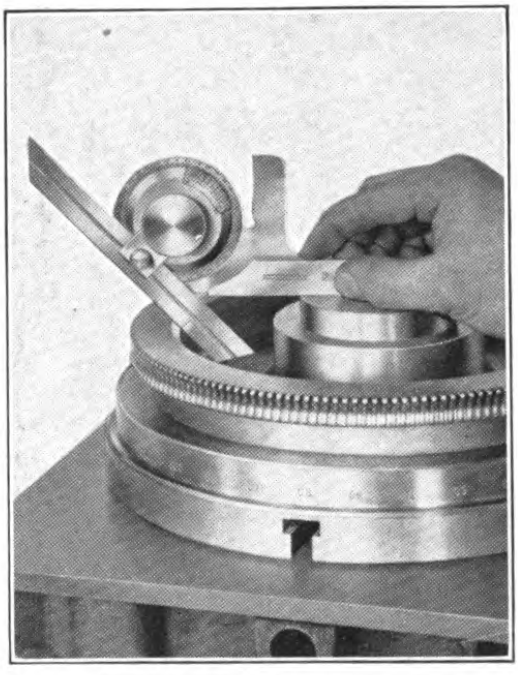


Fig. 134. Measurement of angular clearance on Ring Gear

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In order to use a protractor accurately the position of the zero line on Vernier must be known in relation to the 90° setting. That is, if the angle at which the protractor is set is greater than 90°, the relation of the zero position for the setting must be known, as the protractor graduations run from 0 to 90° then to zero again and then to 90° and so on around its entire graduated circumference.

The reading is obtained direct for angles less than 90°.

When the protractor is used to measure angles greater than 90°, the angle is the difference between the figured setting of the protractor and 180°. Some users simply add to 90°, the angle represented by the distance the zero on the Vernier was moved beyond the 90° setting. Thus, if the zero is on the 80° setting it means (90° − 80°) or 10° should be added to the 90° setting, giving an angle of 100°, or by the first method the reading would be 180° minus 80° or an angle of 100°.

Care should always be taken in determining the angle to be added to 90° or subtracted from the 180°.

Working to an Angle on a Machine. — The principle of setting a machine to work to an angle is similar to the setting of a protractor; the direction of the zero line must be known.

In a Lathe. — Angular work is often turned with a tool held in a compound rest. Figs. 120 and 135 to 138 illustrate a compound rest. The zero line of a compound rest, as in Fig. 136, is at right angles to the center line, *Cc*, of the lathe, the zero line being parallel to *AO*. The flat side of a plate, or disk, can be faced off with the compound rest set at zero.

Angles of Bevel Gear Blanks are usually figured from a plane perpendicular to the axis, as, in Figs. 136 and 137, the angles are figured from *AO*, which is perpendicular to the axis *Cc*. In turning to angles figured in this way the setting of the compound rest is just like the figures on the drawing: thus, in Fig. 136, the drawing calls for 21° for the angle *AOB*, and the rest is set to 21°. In Fig. 137 the angle *AOC* is 66° and the rest is set at 66° and on the opposite side of zero from the previous setting.

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There may, however, be a technical reason for figuring the angles of a bevel gear blank from the axis *Cc*; in fact, a draftsman who has never worked in a machine shop will probably figure them from this axis.

To turn to an angle figured from the axis, the compound rest must be set to the complement of the angle. Thus, if the angle

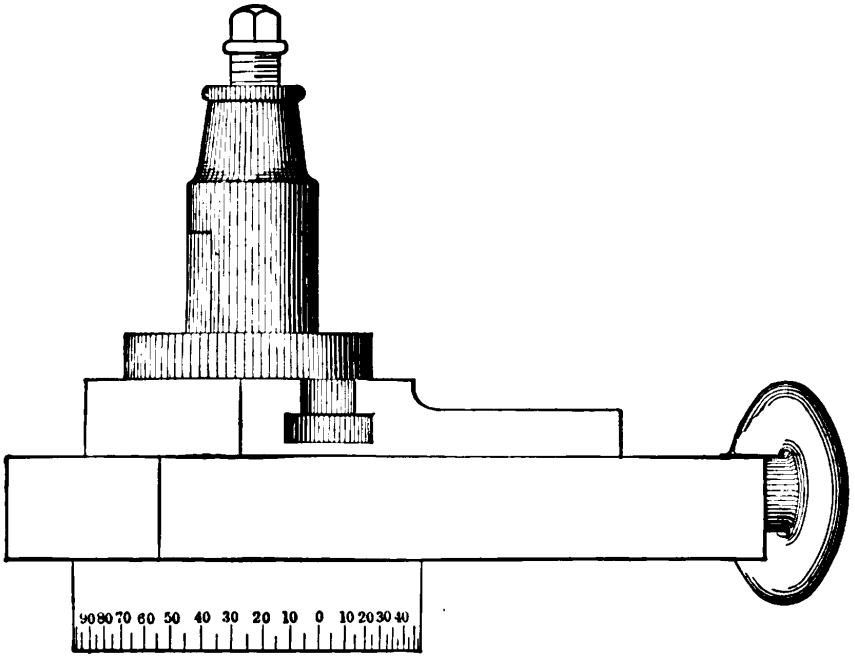


Fig. 135. Compound Rest

CcO, 69°, Fig. 136, is called for, subtract 69° from 90°, and the remainder, 21°, is the setting for the compound rest.

It is better to figure the angles of a bevel gear blank from a line perpendicular to the axis, as in Figs. 136 and 137, to correspond to the figuring of the compound rest. The angles are also more easily measured from a line perpendicular to the axis than from a line parallel to the axis.

In Fig. 138 a beveled or tapering piece is to be turned, in which the side *ao* makes 50° with the side *eb*. In order to set the compound rest the angle *coa* must be known. By a law of geometry *coa* is the complement of the angle that *oa* makes with the

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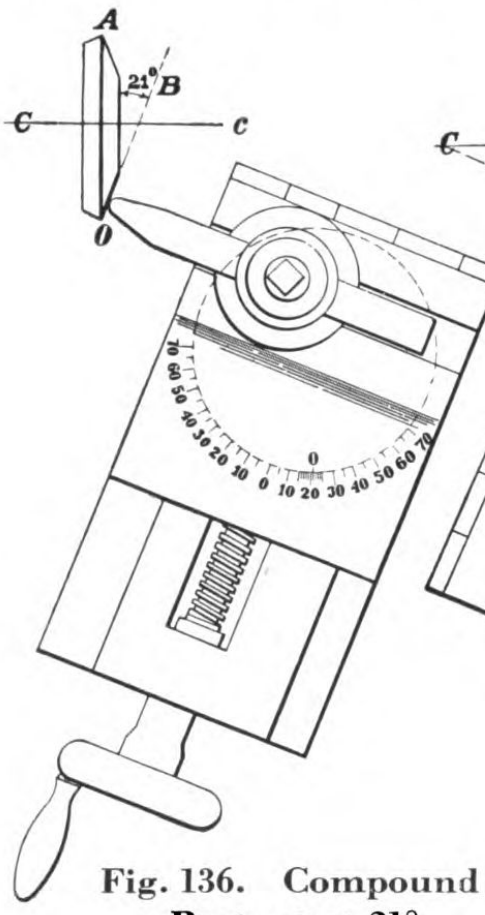


Fig. 136. Compound Rest set at 21°

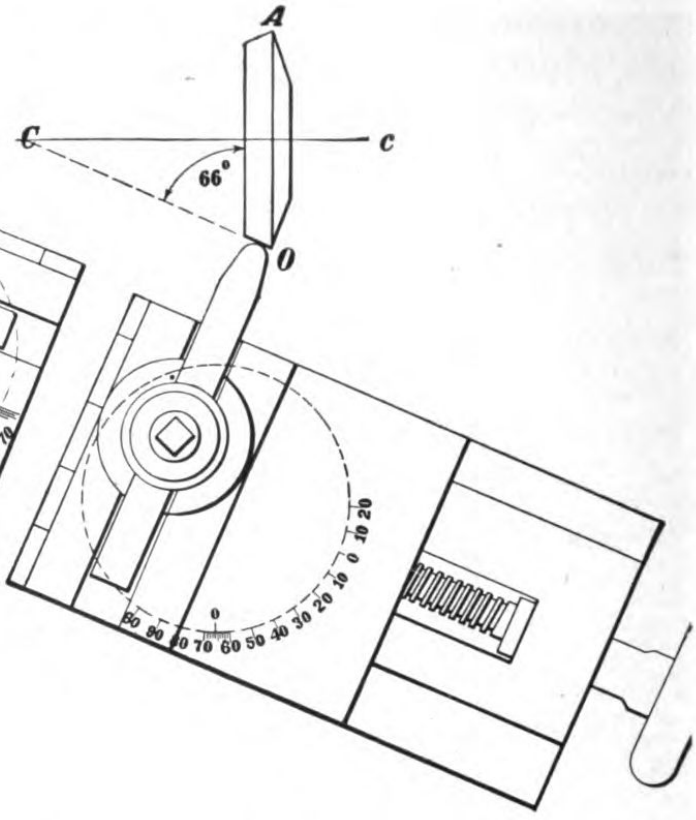


Fig. 137. Compound Rest set at 66°

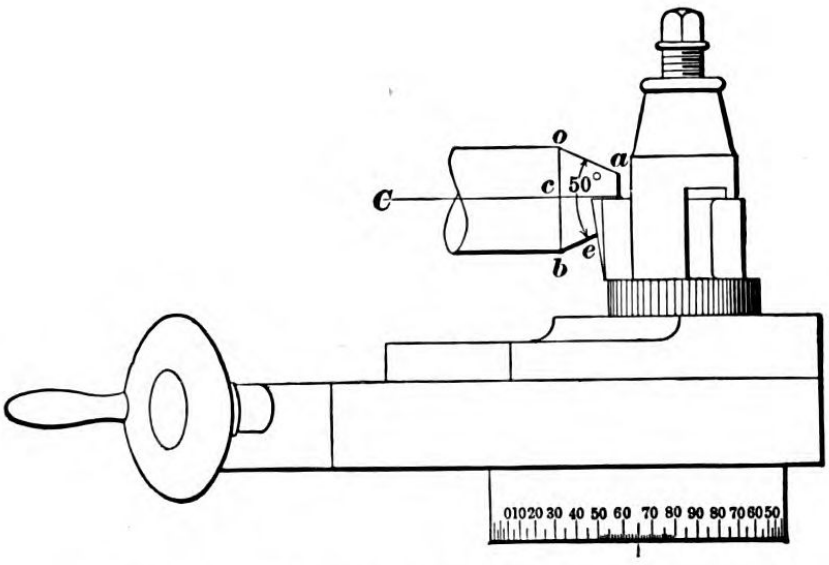


Fig. 138. Compound Rest set at 65°

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center line *Cc*. The beveled part being symmetrical with the center line, the angle which *oa* makes with *Cc* is half of the whole angle 50°, or 25°. 25° subtracted from 90° gives 65° for the angle *coa* which will be the setting of the compound rest.

A Planer Head is figured to read zero when the tool slide is vertical, as in Fig. 139. In other words, when the slide is set

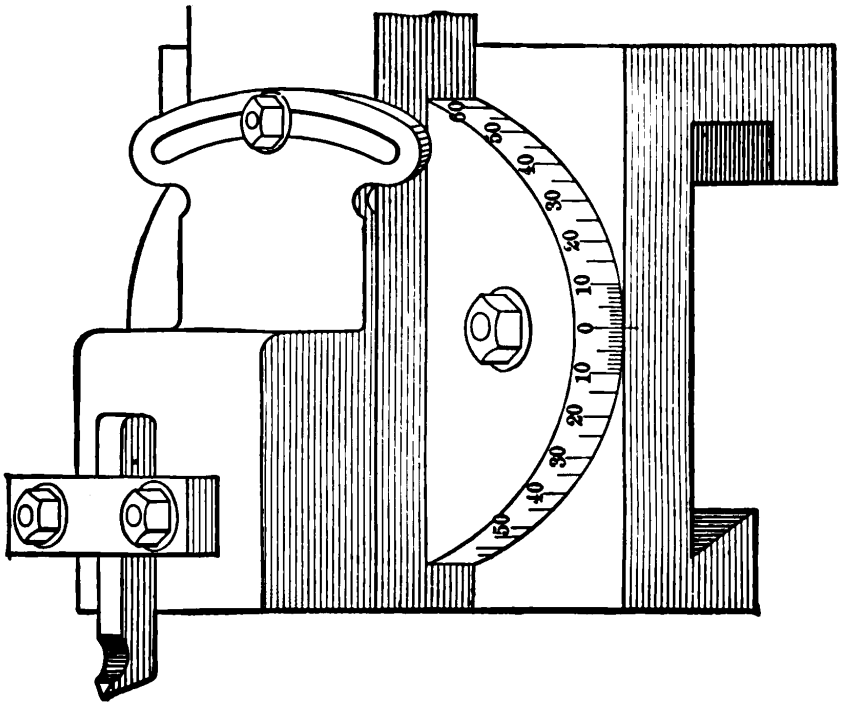


Fig. 139. Planer Tool Slide set Vertically at 0°

to zero, and the vertical feed is in, the tool will plane straight up and down, or at right angles to the top of the table. If a drawing shows an angle measured from a vertical line, as in Fig. 140, the tool slide is set to the degrees called for on the drawing. The side *AO* is parallel to *BC*, and the piece is fastened so that *BC* either rests on, or is parallel to, the top of the table. The angle of the side *OB* with the vertical line *OD* is not easily measured with a protractor, because the vertical line from which to measure is not available. It is very seldom that a planed angle can be measured with the protractor set to the same number of degrees as that to which the planer tool slide is set. When an angle is measured from a vertical surface of the piece to be planed,

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a protractor will measure the angle if it is set as the planer tool slide would be set to plane the angle; but it is not often that an angle is measured from a vertical surface. A vertical surface corresponds to the vertical line *OD*, Fig. 140.

The angle *AOB*, Fig. 140, equals the angle *BOD* plus the right angle *AOD* which equals 10° + 90° = 100°. To obtain the setting for the protractor we subtract 100° from 180° giving 80°. Thus, the protractor, Fig. 142, which is set at 80°, is used to measure the angle *AOB* which is 100°. Since the sum of the angles *AOB* and *OBC* is 180°, the angle *OBC* is equal to 180° minus the angle *AOB*, or 180° − 100° = 80°.

In Fig. 141, a protractor is measuring the angle *OBC*. If pre-

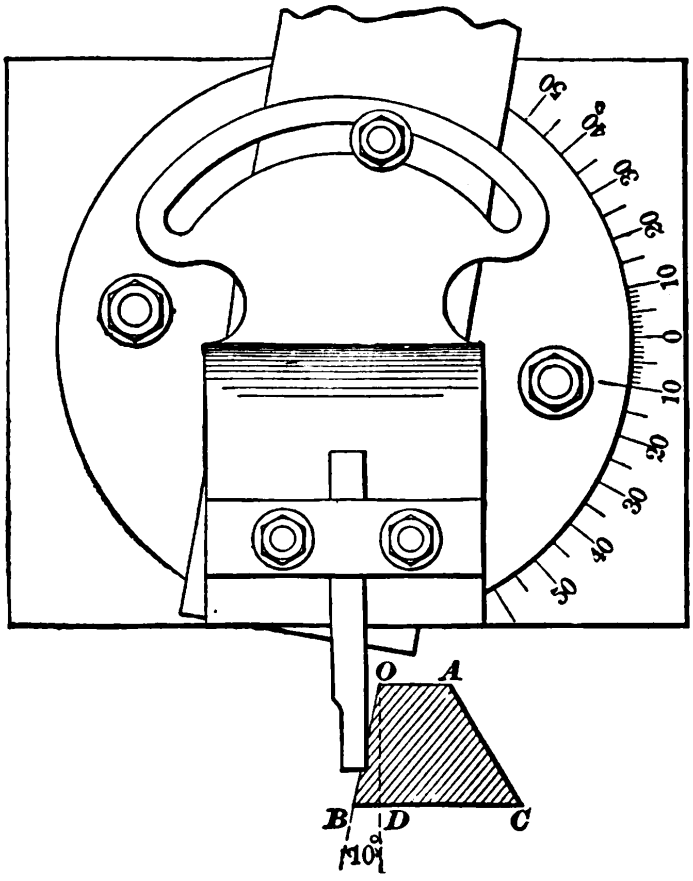


Fig. 140. Planer Tool Slide set at 10°

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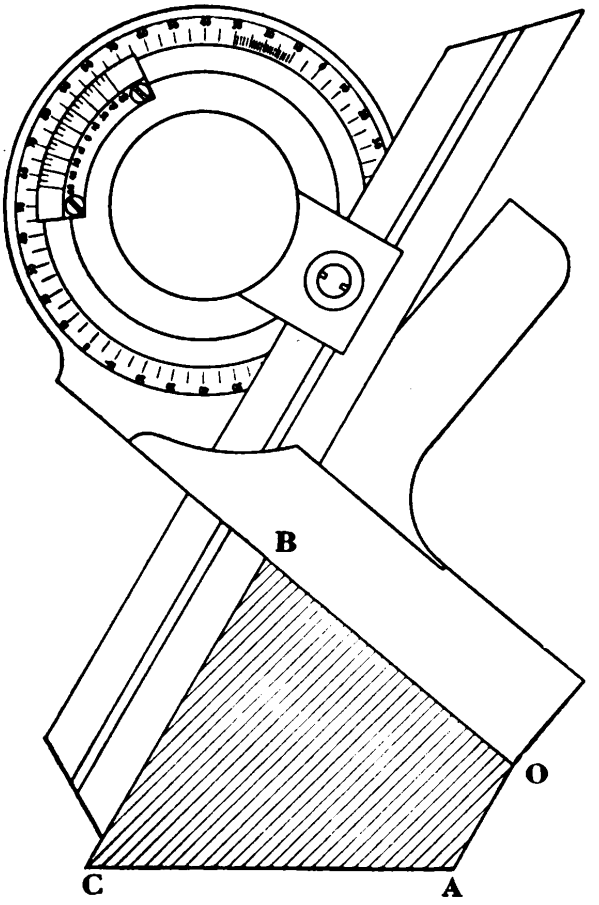


Fig. 141. Protractor Measuring Angle OBC, 80°

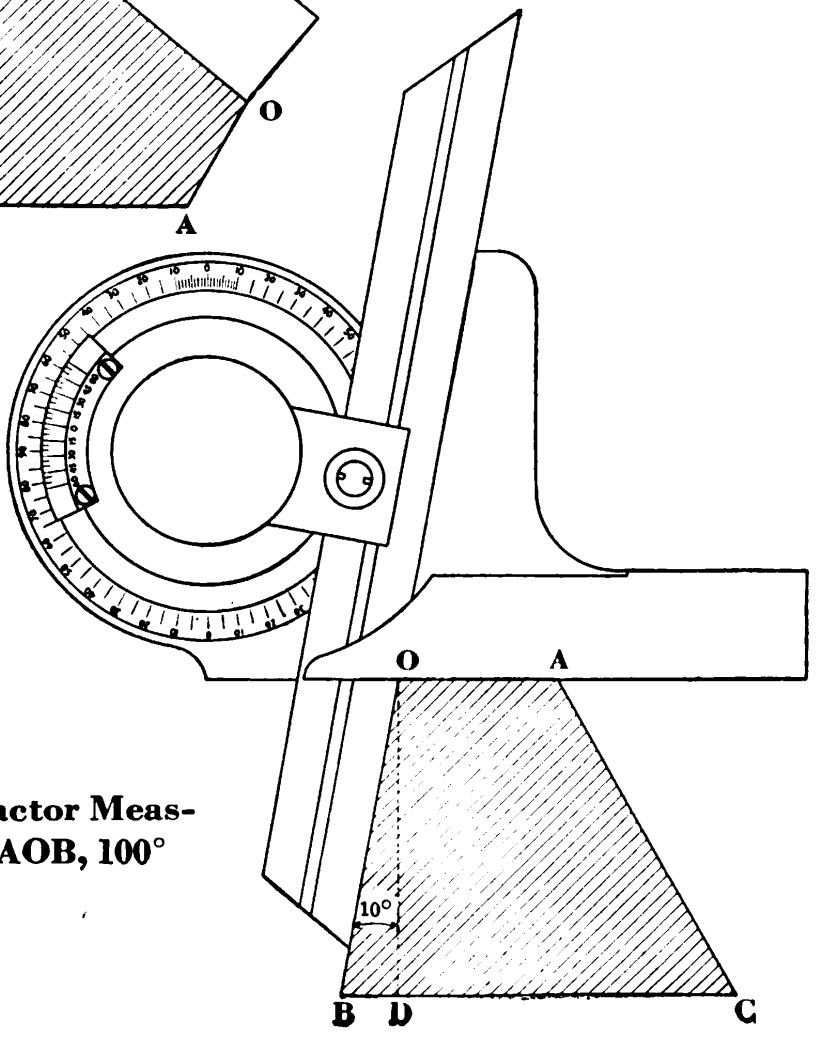


Fig. 142. Protractor Measuring Angle, AOB, 100°

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ferred, the angle *OBC* may be regarded as the remainder after subtracting *AOB* from 180°; 180° − 100° = 80° as in Fig. 140.

Angle Measured from the Table, or from a Horizontal Line. — In order to plane an angle that is measured from a horizontal line, when the angle is less than 90°, the angle is subtracted from 90°; the remainder being the setting of the tool slide. Thus, in Fig. 143, the angle *ACB* is 60°, which being sub-

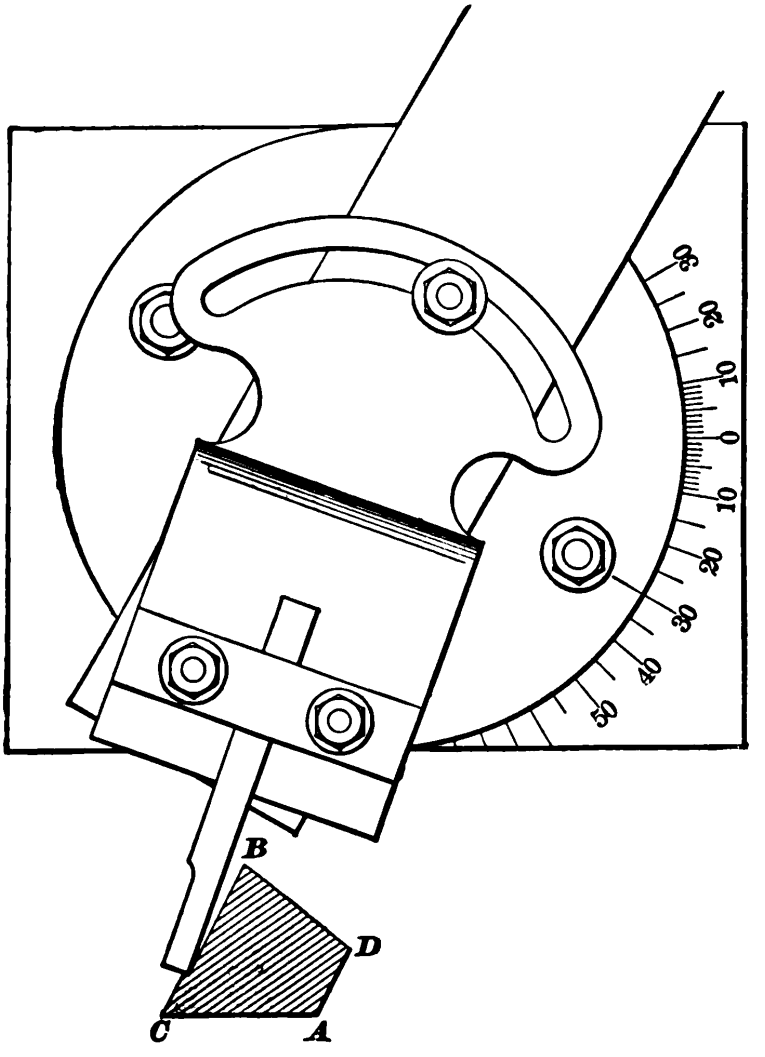


Fig. 143. Planer Tool Slide set at 30°

tracted from 90° leaves 30° as the setting of the tool slide. The principle of the foregoing is shown in Fig. 128.

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To plane to an angle greater than 90° from a horizontal line, subtract 90° from the angle and the remainder will be the setting of the tool slide. Thus, to plane to an angle of 115° from the horizontal, subtract 90° from 115° and the remainder 25° is the setting for the tool slide. See Fig. 129.

Chucks and Chucking. — Chucking is an expression that is often used to distinguish between two kinds of lathe work: work wherein the piece is held in a chuck and work wherein the piece is held between centers. The chuck itself is an adjustable work holding device. (*Note:* The magnetic chuck may be said to be in a class by itself inasmuch as it holds the work by magnetic attraction.) See page 189.

The jaws of the ordinary chuck are adjustable to accommodate work of different diameters. In the case of the lathe chuck it can be screwed on the threaded end of the lathe spindle. A drill chuck fits on the tapered end of an arbor while the other end of the arbor, also tapered, fits into the tapered hole of the spindle.

Types of Chucks. — There are at least five kinds of chucks in common use: universal chucks, independent chucks, combination chucks, drill chucks, and draw-in chucks. The jaws of chucks are furthermore distinguished by four types: lathe jaws, drill jaws, milling machine jaws, and brass jaws. Lathe jaws are used to hold lathe work from the outside or inside and are usually for larger diameters. Drill jaws are made suitable for holding rods and drills, even of very small diameter. Milling machine jaws are designed for the requirements of the milling machine. Brass jaws are made with contact pieces of brass that are fitted to the jaws and which can be readily slipped out.

Universal Chuck. — These chucks, Fig. 144, are made so that when a wrench is applied to any one of the jaws all the jaws move concentrically, inward or outward. Universal chucks are ordinarily used for work of regular shape. For small lathes they are made in several sizes.

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Independent Chuck. — The jaws of an independent chuck, Fig. 145, move independently of each other. This type of chuck is preferred for rough and irregular work, because, by the independent movement of the jaws, irregularly shaped pieces can be trued with greater facility than with the universal chuck. For general work the independent chuck with four jaws is the most practicable type. Concentric rings are to be found on some chucks of this type to assist the operator in setting the jaws.

Combination Chuck. — By a device on the back of a combination chuck, Fig. 146, the mechanism can be meshed or unmeshed so that the jaws will move independently as in the case of the independent chuck or concentrically as in the case of the universal chuck. This chuck also has concentric rings cut on its face so that when it is desired to use the chuck as a universal chuck, the jaws can be lined up with one of the rings and the mechanism thrown into mesh to furnish the universal action. Combination chucks fulfill the requirements for both independent and universal chucks, but they require more care to keep them in good condition.

Drill Chuck. — This type of chuck, Fig. 147, is used to hold drills, rods, and work of like character. It operates like a universal chuck.

Draw-In Chuck. — The draw-in chuck, Fig. 148, is used on some engine lathes and on many turret lathes and screw machines. It is a common type in use on toolmakers' and watchmakers' lathes. In operation, the work in the form of bar or rod stock, is usually passed through the spindle and up to the draw-in chuck. The work enters the chuck and can be held securely. Bolts, nuts, screws, and a variety of shapes may be turned, drilled, and tapped directly from the bar, without first having to be cut off and handled again. The mechanism for opening and closing the chuck operates while the spindle rotates and it is operated by a hand wheel located where the stock enters the spindle or by a lever on the head stock.

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Care of Chucks. — Chucks should receive care and attention in order to preserve their accuracy. They should be kept clean and free from grit, and oiled frequently. Never force a chuck by using a pipe as an extension on the chuck wrench. Exercise particular care in mounting or removing chucks from the spindle

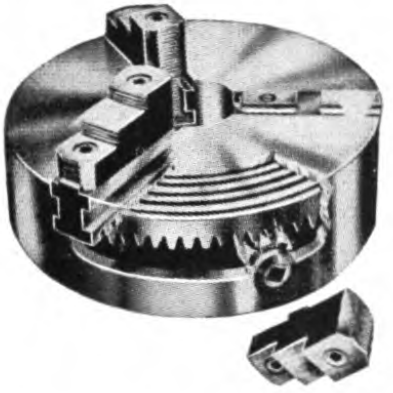


Fig. 144. Universal Chuck



Fig. 145. Independent Chuck

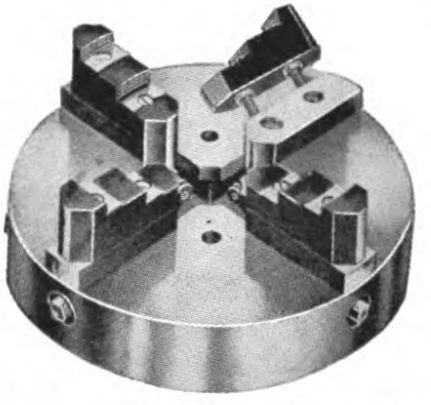


Fig. 146. Combination Chuck

of the lathe. Before mounting, remove the " live " center and fill the taper hole with cotton waste. Clean and oil the threaded end of the spindle and the internal thread of the chuck. Never use power in screwing on the chuck; hold it square with the nose of the spindle, and resting in the hollow of the right arm. The left hand can then rotate the spindle by pulling the belt. It is a mistake to run the chuck up on its thread so fast that it brings up with a shock; this only increases the difficulty of

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removing it. To remove a small chuck, place a monkey wrench on one of the jaws, and by a smart blow of the hand on the handle of the wrench, it can usually be started. For heavier chucks rotate the chuck against a block of wood held between a jaw of the chuck and the V ways on the back of the machine. When

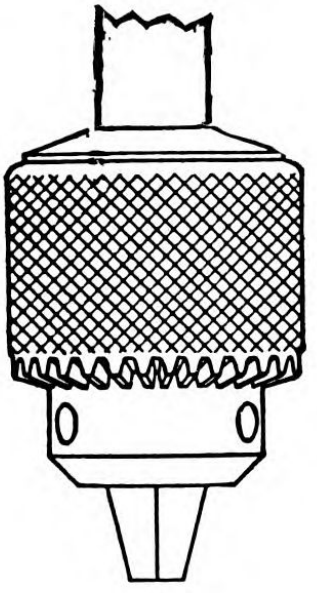


Fig. 147. Drill Chucks are made in a Number of Sizes. They are usually Mounted on a Tapered Shank

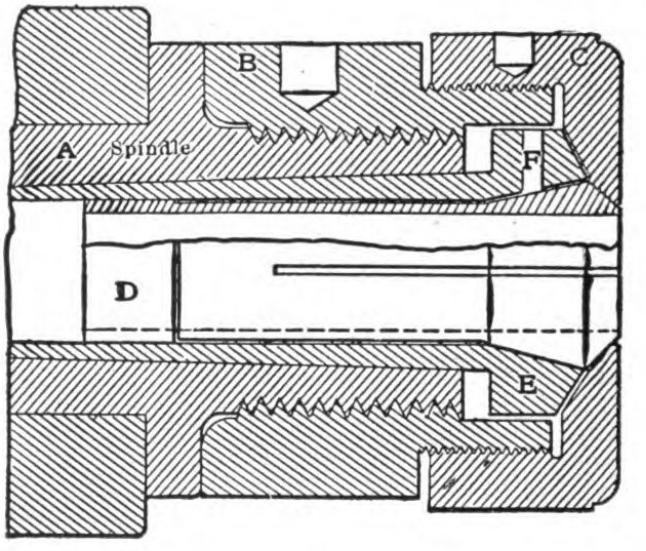


Fig. 148. Draw-In Chuck or Collet

A, lathe spindle; B, sleeve; C, cap; D, collect; E, taper sleeve; F, pin

removing or mounting a heavy chuck, it is good practice first to lay a board across the ways of the lathe. The board will serve as a rest for the chuck as it is put on or taken off.

Holding the Work. — Clamp the work firmly in the chuck before starting to machine it. Care should be taken not to spring light work by screwing the jaws too tight.

Truing Work. — Before any machining can be done on a piece it should be trued in the chuck; that is, the jaws should be adjusted so that the piece will rotate as nearly concentric with the axis of the spindle as possible. By holding a piece of chalk and resting the hand on the front ways of the machine, the chalk

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can be moved slowly toward the work and the high spot will be the part of the piece first to receive a chalk mark. By withdrawing the opposite jaw or jaws and closing the jaw near the mark, the piece can be moved sufficiently so that it will rotate truly. Greater accuracy can be secured by using a dial test indicator as shown in Fig. 90.

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CHAPTER V

Drills, Drilling and Drilling Machines

The Twisted Drill is made from flat stock rolled thinner at the middle than at the edges and then twisted. The twisted drill resembles the fluted twist drill. The shank may be flat or round. Some of the advantages of this drill are that they are economical to make, have ample clearance for chips, and can be more readily hardened and tempered than the fluted twist drill.

Twist Drills are made of carbon steel or alloy steel (high speed steel), from round stock with spiral flutes cut by a milling cutter or formed by rolling or forging. They have two, three, or four cutting edges. The most common type, however, is the two lipped twist drill, ground so that the included angle is about 118°. The three or four lipped drills are used to enlarge holes, whether cored or drilled.

The ordinary twist drill has two flutes only and is generally cylindrical throughout its length. As a matter of fact, however, it is usually tapered slightly and toward the shank. This is intended for clearance and is so slight that it is negligible. In addition, for further clearance, back a short distance from the cutting edge of the flute, it is eased off to a smaller diameter back to the next flute. This reduces the friction between the drill and the walls of the hole. For a short distance back from the edge of each flute there is a section that is part of a full circle. It is this section that determines the size of the drill and steadies the cutting action. Should this cutting section become worn away near the point, the drill will not cut and it becomes necessary to grind back the point of the drill until it is restored again. It is well to remember these two clearance features of a drill, particularly when measuring the diameter of the drill with micrometer calipers.

The twist drill is a most satisfactory type for general work. Its

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cylindrical shape tends to control the direction of the hole and to maintain a steady cutting action between the cutting edges and the work. The cutting edges remove the metal by a cutting action rather than by a scraping action. The flutes of a twist drill aid in removing the chips and assist materially in urging the drill through the work.

Two Lipped Straight Fluted Drills. — These drills are cylindrical in shape and made from round stock. The flutes are straight and give this type an advantage in drilling through soft materials like brass or for use where curling chips are troublesome. In addition, where the work is thin and the drill must penetrate, this type breaks through better than the twist drill and with less risk of breaking the drill due to its straight flutes.

Drill Shanks. — Twist drills under 1/4" in diameter are almost always made with a straight shank, while the shank on the larger sizes may be either straight or tapered. The tapered drill shanks usually have the Morse Standard Taper. (See Table, page 297.)

Twist Drill Sizes and Steel Wire Gages. — The differences in the systems of identification of small twist drills and steel wire gages are often confusing to those working with these tools. Twist drills frequently have their drill sizes indicated by letters or figures as well as by decimal parts of an inch which create some confusion particularly with drills of small diameters and while there have been efforts to standardize in the use of certain sizes this practice is not general. Still further confusion is caused by the similarity of certain of the wire gage sizes. A safe plan in ordering drills is to give the size required in decimals if there is any doubt as to the drill gage number or letter.

Drill Points and Sharpening. — The form of the drill point, Fig. 149, should conform to the following rules:

(1) The cutting edges or lips should make a uniform and exact angle with the axis of the drill and that angle should be 59° except under unusual conditions, when a larger angle is sometimes used.

(2) Cutting edges should be the same length.

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(3) The clearance and angle back from the cutting lips may be from 12° to 15°. The best clearance at the cutting edge for twist drills, when used for general work, is 12°; for soft metals, 15°.

Great care should be taken in sharpening drills to maintain the above requirements. As a regular practice, hand sharpening

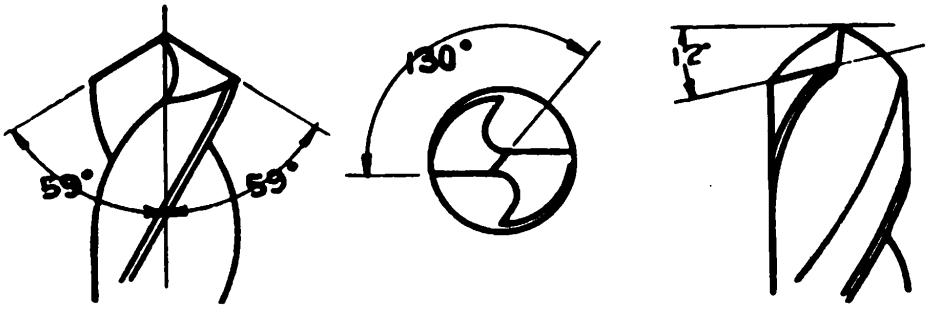


Fig. 149. Drill Point Angles

is not to be recommended. It is usually haphazard and only approximately correct.

Lubrication of Drills. — Lubricants are used on drills not so much for purposes of lubrication as to distribute the heat caused by cutting. Too much heat at the point of the drill will, of course, draw the temper of the drill and render it soft. Use plenty of cutting emulsion on wrought iron or steel; for refractory steel, use cutting emulsion, kerosene, or turpentine; for brass, paraffin oil; for aluminum, cutting emulsion, turpentine, or kerosene. Cast iron is usually drilled dry, but a jet of air can be used to advantage. Some drills have oil holes drilled down through the flutes before the drills are twisted; others have grooves cut around the drills which provide a recess for copper tubes to conduct the oil directly to the cutting point of the drill.

Drill Speeds and Feeds. — The question as to what speed a drill may be run depends upon the size of the drill and the composition of the material which is to be drilled. Usually it is better for the operator to use his own judgment; he alone knows the condition of his drill and the hardness of the work to be drilled. See page 291 for table on feeds and speeds for drilling.

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There are two kinds of steel used in the manufacture of drills: carbon steel, called tool steel, and alloy steel, called high speed steel. Alloy steel (high speed steel) contains a varying percentage of manganese, chromium, nickel, tungsten, and vanadium. Drills made from alloy steel can be run from two to three times faster than those of carbon steel. Carbon steel drills, however, are satisfactory except where unusual service is expected.

The feed of a drill is determined also by the conditions that surround the job. A fair estimate would be .006″ to .010″ feed per revolution of the drill.

Drilling Machines. — For purposes of drilling holes in metal, there is a variety of machines each of which has its particular advantages for certain kinds of work. Among those in most common use we may name portable drills, sensitive drills, drill presses, column drills, radial drills (traveling head drills), multiple spindle drills and horizontal drills.

Portable Drills. — Under the head of portable drills we might classify all types of electrical drills, compressed air drills, flexible shaft drills, breast drills and ratchet drills. Drills of this type are usually compact in design and readily portable. They are particularly adaptable to repair work or drill work where it is more practicable to bring the drill to the work than to bring the work to the drill.

Sensitive Drills. — For very light work where it is necessary to feel the action of the drill point as it penetrates the work, the sensitive drill has been designed. It is frequently used for center drilling in shops where a special machine for this purpose is not practicable. No gears are used to drive the spindle. The drive is entirely by belts. Nothing but a hand lever, pinion, and rack on the spindle intervenes between the hand of the operator and the drill point. The spindle is bored out to a No. 1 Morse Taper. Drills with shanks of this taper can be used direct, or a drill chuck (with a shank) to fit this taper can be used.

Drill Press. — The drill press, Fig. 150, is designed for heavier work. It has back gearing similar to a lathe together with a

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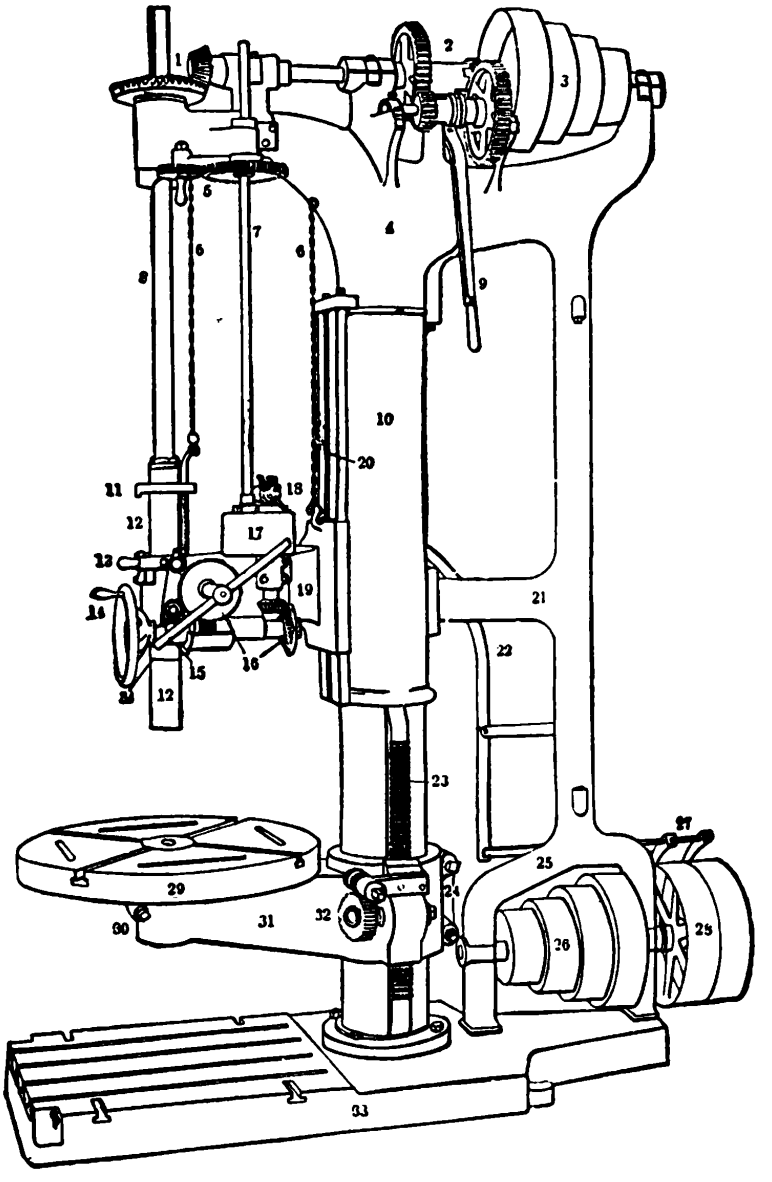


Fig. 150. Parts of a Drill Press

1. Main driving gears, bevel
2. Back gears
3. Upper cone pulley
4. Frame
5. Feed gears
6. Counterweight chains
7. Feed gear driving shaft
8. Spindle
9. Back gear lever
10. Column
11. Automatic spindle feed stop
12. Spindle sleeve
13. Feed trip lever
14. Hand feed wheel
15. Spindle quick return lever
16. Feed gearing
17. Feed box
18. Feed change handle
19. Sliding head
20. Sliding head ways
21. Back brace
22. Belt shifter
23. Rack for elevating table
24. Table arm clamping screws
25. Pulley stand
26. Lower cone pulley
27. Belt shifting fingers
28. Tight and loose pulleys
29. Table
30. Table clamping screw
31. Table arm
32. Table elevating gear
33. Base
34. Ball thrust spindle bearing

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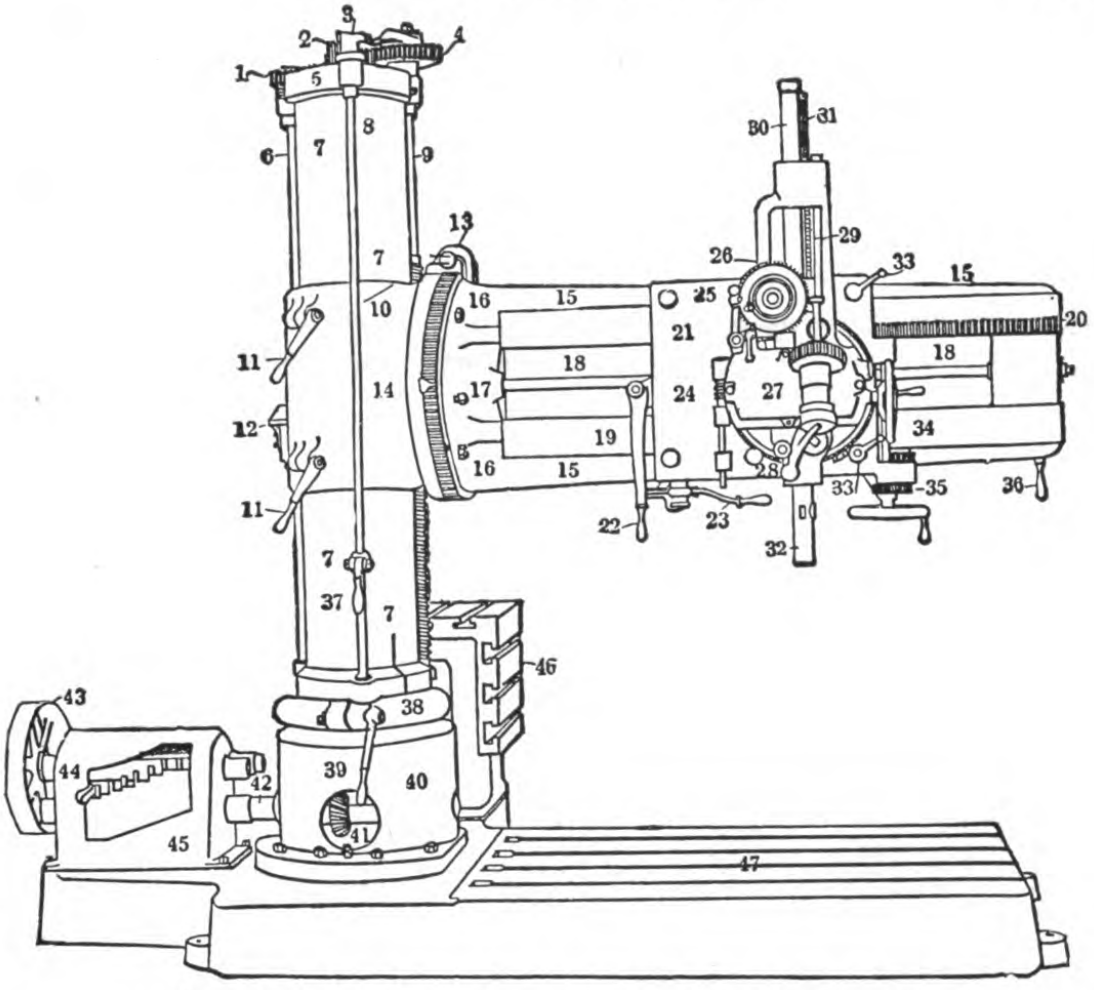


Fig. 151. Parts of a Universal Radial Drill

1. Vertical driving shaft gear
2. Center driving shaft gear
3. Elevating tumble plate segment
4. Elevating screw gear
5. Column cap
6. Vertical driving shaft
7. Column sleeve
8. Elevating lever shaft
9. Elevating screw
10. Arm girdle
11. Arm clamping lever
12. Spindle driving miter gear guard
13. Arm rotating worm
14. Arm indicating pointer
15. Full universal arm
16. Arm clamping nuts
17. Arm locating pin
18. Arm driving shaft
19. Arm ways
20. Spindle head traversing rack
21. Saddle
22. Spindle reversing lever
23. Back gear lever
24. Spindle head swiveling worm
25. Spindle feed trip lever
26. Depth gage dial
27. Universal spindle head
28. Spindle quick return lever
29. Spindle feed rack worm shaft
30. Spindle
31. Spindle feed rack
32. Spindle sleeve
33. Saddle clamping lever
34. Spindle feed handwheel
35. Spindle head traversing gear
36. Arm swinging handle
37. Arm elevating lever
38. Clamping ring
39. Clamping ring handle
40. Column
41. Main driving miter gears
42. Driving shaft coupling
43. Driving pulley
44. Speed change lever
45. Speed change case
46. Box table
47. Base

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power feed. The principal difference between the drill press and the sensitive drill is its greater weight and rigidity, the strength and size of its moving parts, the range of its spindle speeds, its power feed, and its greater power due to the use of cones and back gears.

Radial Drills. — In the case of the radial drill, the drill spindle is carried in a traveling head on a horizontal arm. The head that carries the spindle can be located at any point in the range of the machine along the arm. In addition, the horizontal arm can be swung in a horizontal plane, raised or lowered and clamped rigidly in position. These machines are used for jobs where the work is so heavy that it is more practicable to bring the drill into position by means of the horizontal arm than to move the work.

Universal Radial Drills. — Although similar in design to radial drills, these machines have a traveling head that can be swung to any angle in a vertical plane. The horizontal arm can be swung in a horizontal plane and, in addition, it can be swiveled on its axis, thus enabling the machine to drill holes at any angle. See Fig. 151.

Multiple Spindle Drill. — This type of drill, Fig. 152, is used on production work requiring holes of a variety of sizes. Two or more spindles are driven from the same driving shaft by worms and worm gears or belts. The table is not usually adjustable except on certain types. The spindles can be moved along the cross rail (on some machines) and set the required distances apart within the range of the machine. This type of drill is very useful for plate work, structural iron or light work requiring a number of holes in a straight line.

Universal Multiple Spindle Drill. — This type of drill, Fig. 153, has a cluster of drill spindles held in a head that can be raised or lowered and clamped in position on the column. The spindles are driven by means of universal joints and can be set variable distances apart. Jigs should be used when work is to be done with spindles driven by universal joints.

Reaming. — It must be remembered that it is practically impossible to drill a hole with a high degree of accuracy. The

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reamer is used to finish holes to size. There are two classes of reamers: chucking reamers, used for rough reaming on a machine,

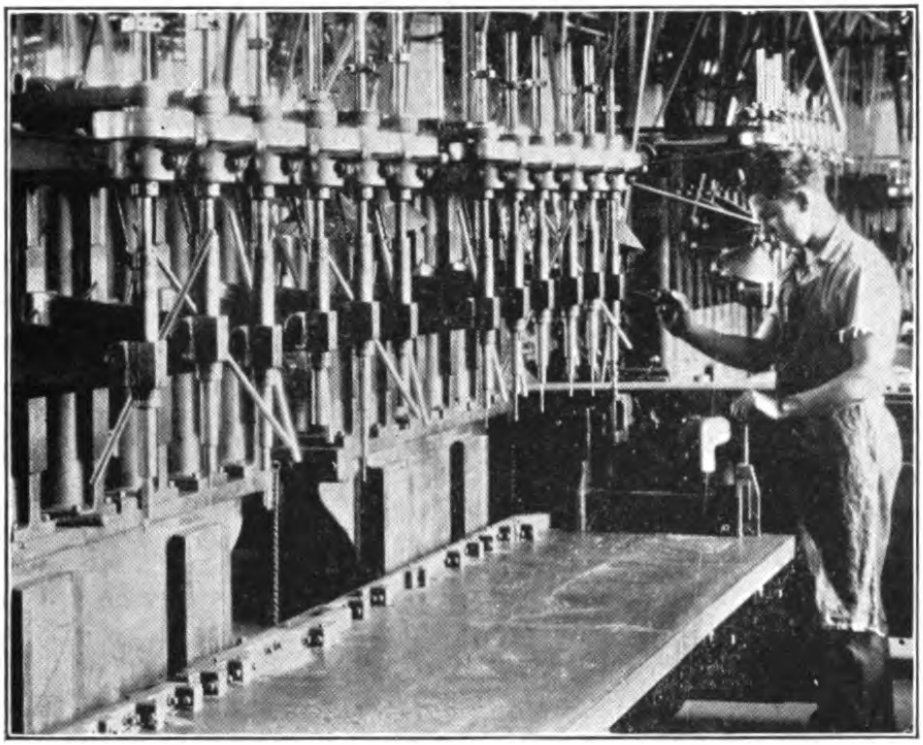


Fig. 152. Multiple Spindle Drill in Operation

and finishing reamers that may be used by hand or on machines.

Ordinarily .005″ to 1/64″ should be left after drilling in order to finish ream cast iron, and .005″ to .010″ for steel or brass.

Holes that have been drilled by chucking drills are usually left about 1/64″ undersize. By using the chucking reamer in the next operation, the diameter of the hole can be brought to within .005″ of the specified size. The finishing reamer brings the hole to its true diameter. On a chucking reamer a slight bevel appears at the ends of the teeth. The cutting edges produced by this bevel enable the chucking reamer to remove stock to a depth of 1/64″, more or less. The straight part of the flutes tends to line up the tool and smooth the walls of the hole. The rose chucking reamer has about half as many flutes as the ordinary chucking reamer with a taper that is very much greater. For

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this reason it is capable of removing more stock and with greater facility than the plain chucking reamer.

The Hand Reamer is used to give the hole a smooth finish and correct diameter. This tool should not be expected to remove a considerable amount of stock. It is intended only to line up the hole and leave it with its required diameter. A reasonable amount to expect the hand reamer to remove is .007″, and holes should be drilled with this in mind when the hand reamer is used. Hand reamers are slightly tapered at the end for a distance of 3/8″ to 1/2″ and they are .010″ to .012″ smaller at the end. This taper facilitates the entrance of the reamer and enables it to make a good start. Use good oil on a hand reamer in working on steel or wrought iron; cast iron should be reamed dry, but it is a good plan to place the work in a position so that the chips will fall down through the hole. All hand reaming should be done in a vertical position if possible.

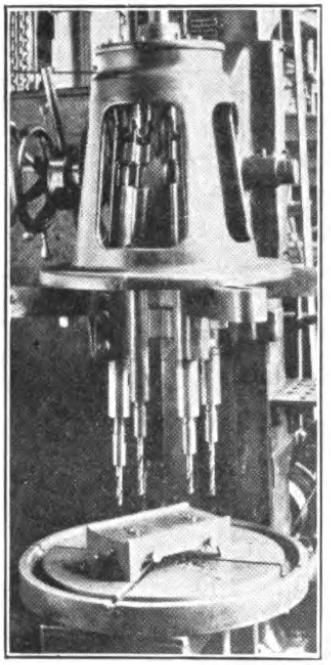


Fig. 153. Universal Multiple Spindle Drill

A solid reamer cannot be sharpened without reducing its size; for this reason every precaution should be taken to preserve its edges. This disadvantage is overcome by the inserted tooth reamer which, on the other hand, is more expensive. The expanding reamer can be increased in size to compensate for wear by adjusting a nut at the end. This type, however, is not considered wholly satisfactory for high-class work due to the fact that the expansion of its blades is not uniform along its whole length. Reamers are available for taper holes, taper roughing and taper finishing.

Counterboring. — The cutting edges of a counterbore are at right angles to the center line of the tool. In advance of the

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cutting edges, a pilot acts as a centering guide to direct and line up the tool as the cut progresses.

Counterbores for screw holes are usually made in sets of three; one has a body of the same size as the head of the screw and with a pilot of the same size as the hole that admits the body of the screw; another has a body of the same size as the head of the screw with a pilot of the same size as the tap drill; the third has a body of the same size as the body of the screw and with a pilot of the same size as the tap drill.

Counterbores usually have four flutes cut to a right-hand 15° spiral. For brass work the flutes are straight. Frequently small counterbores are made with but three flutes. For general work the cutting edges should have a clearance of from 4° to 5°. Any relief that may be required should be on the end of the body, never on the cylindrical surface.

Tapping. — Taps are internal threading tools. They are usually made in sets of three. A thread is cut on one end and square flats on the other. Ordinarily the thread of a tap is not backed off, but on the chamfered or tapered end it may be ground with a relief. Three or more flutes are milled through the threads after which the piece is hardened, tempered and ground.

Some of the more common types of taps are: hand, machine, pipe, stay bolt, boiler and pulley taps. Hand and machine taps are in general use.

Of the various kinds of threads that are cut on taps there are several kinds known as standard. Among the more common are the American National Standard, Whitworth or British Standard, Système International, Acme or 29° and Brown & Sharpe 29° Worm Thread. See Figs. 110 to 115.

In drilling a hole to accommodate a certain size of tap, it is necessary that the hole should be the proper size. Otherwise the thread may be cut too deep or not deep enough. The tables of taps and corresponding drills for American National Coarse and Fine Threads, American National Pipe Threads, V Threads, Whitworth or British Standard Threads are shown on pages 286 to 290.

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Hand Tapping. — Inasmuch as hand taps are in more general use, a description of these will do for the other kinds. The three hand taps to a set are called, in the order in which they are used in tapping a hole, taper, plug, and bottoming, or No. 1, No. 2, and No. 3. In tapping a hole very little force is needed to urge the tap through. If care has been exercised to start the tap straight, i.e., if it is held vertically and at right angles to the work, it will draw itself through as the thread is cut. No. 1 tap is tapered in order to facilitate its entrance in the hole and so that the metal will be removed gradually to form the thread. On work where a high degree of accuracy is required it is better to start the tap with reference to a square. This is the easiest way to make sure that it is vertical as it enters the work, unless a tapping jig is available.

A tapping jig should be used on all jobs where practicable. Use oil freely on steel and wrought iron. Cast iron and brass should be tapped dry, although sometimes oil is used to make the tap cut more freely. It is an advantage to back the tap frequently as the cut progresses, in order to free the cutting edges from the chips. In the case of a piece of work in which a hole has just been drilled on the machine, it is good practice to center the tap by means of a center inserted in the drill spindle. The spindle may be lowered until the point of the center engages the center hole in the shank of the tap.

By feeding the spindle down as the tap is screwed into the hole by hand, a good uniform thread can be obtained. In the case of a hole that does not penetrate the work, the plug or second tap is used first to start the thread. After running this tap down as far as it will go it may be withdrawn, the hole cleaned out, and the thread finished with the bottoming tap. Of course where a tap can be run directly through the work the taper tap is sufficient.

In machine tapping a frictional tap holder is used. It disengages the tap when the bottom of the hole is reached. In withdrawing a machine tap the machine is reversed and a higher

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speed is used. If the hole is the proper size for the tap and if too much strain is not put on the tap there will be few broken taps. A broken tap may spoil a day. No. 2 tap or plug is used mostly for machine tapping.

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CHAPTER VI

Planing

Planers. — It is well to remember that the most important feature in planing is the setting-up of the work. Planer tools differ little in their general design from lathe tools, and when a tool is correctly set in the head of a planer the effect is similar to a lathe tool set at the center of the axis of the work.

Planer Tools. — Planer tools have about the same rake as lathe tools, but the clearance is less, being from 3° to 5°. In

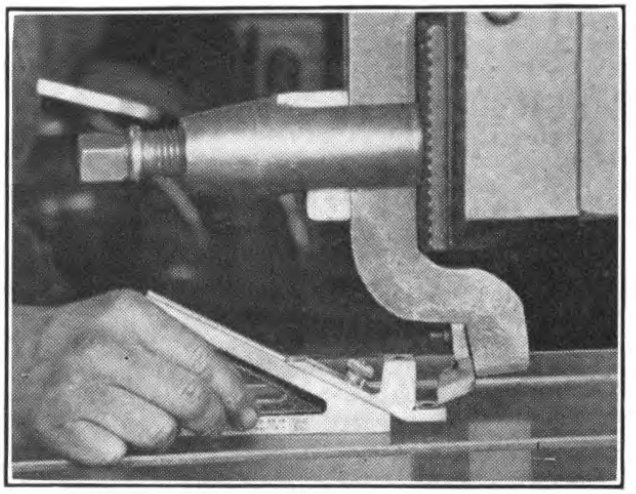


Fig. 154. Planer Gage for setting the Tool at the desired Height. Gage is first set to a Micrometer

addition, they are designed to be heavier and more rigid. Except when planing the sides of a piece, a planer tool is usually set perpendicularly to the table, and clamped with the cutting point as close as practicable to the head in order to avoid vibration and to secure rigidity. To obtain an accurate setting for the height of the tool, notice the method indicated in Fig. 154. A setting made in this way is equivalent in degree of accuracy

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to a micrometer reading. For an approximate degree of accuracy, a scale may be used to make the measurement.

Aligning the Planer. — To plane work requiring a high degree of accuracy it is very necessary that the table and the cross rail be in correct alignment. To accomplish this, loosen the clamping bolts back of the rail and lower the rail toward the table so that the tool barely touches the work. Raise it about an inch to take out back lash, and clamp. Test the alignment of the rail and the table by running the head, with tool clamped in, from one side to the other, using a test block and a piece of paper under the point of the tool to detect any variation from parallel. If a difference is detected, loosen the clamping bolts slightly and tap the high end of the rail with a lead hammer. Repeat the previous operation to see whether the alignment is complete. If the rail is considerably out of alignment adjust the bevel gears on the horizontal shaft at the top of the posts.

To Set Planer Head for a Vertical Cut. — Line up the zero mark on the tool block swivel with the zero mark on the tool block saddle. Loosen the bolt or bolts that hold the clapper box and swing the top toward the operating side of the planer, if the cut is going to be taken on that side, so that the tool will swing away or lift from the work on the return stroke. If the cut is to be taken on the opposite side of the planer, the top of the clapper box should be swung away from the operating side of the planer. Be sure that all bolts are tightened before starting to plane.

To Set for a Bevel Cut. — Loosen the bolts of the tool block swivel and swing the head to the required angle. Tighten bolts. Loosen the bolt or bolts that hold the clapper box and swing it so that the tool will swing away or lift from the work on the back stroke. The direction to swing the tool should be determined and it should be set while the machine is stopped, when the adjustment can be made safely.

Planer Head Graduations. — When the graduations on a planer head are to be read from the vertical and the drawing

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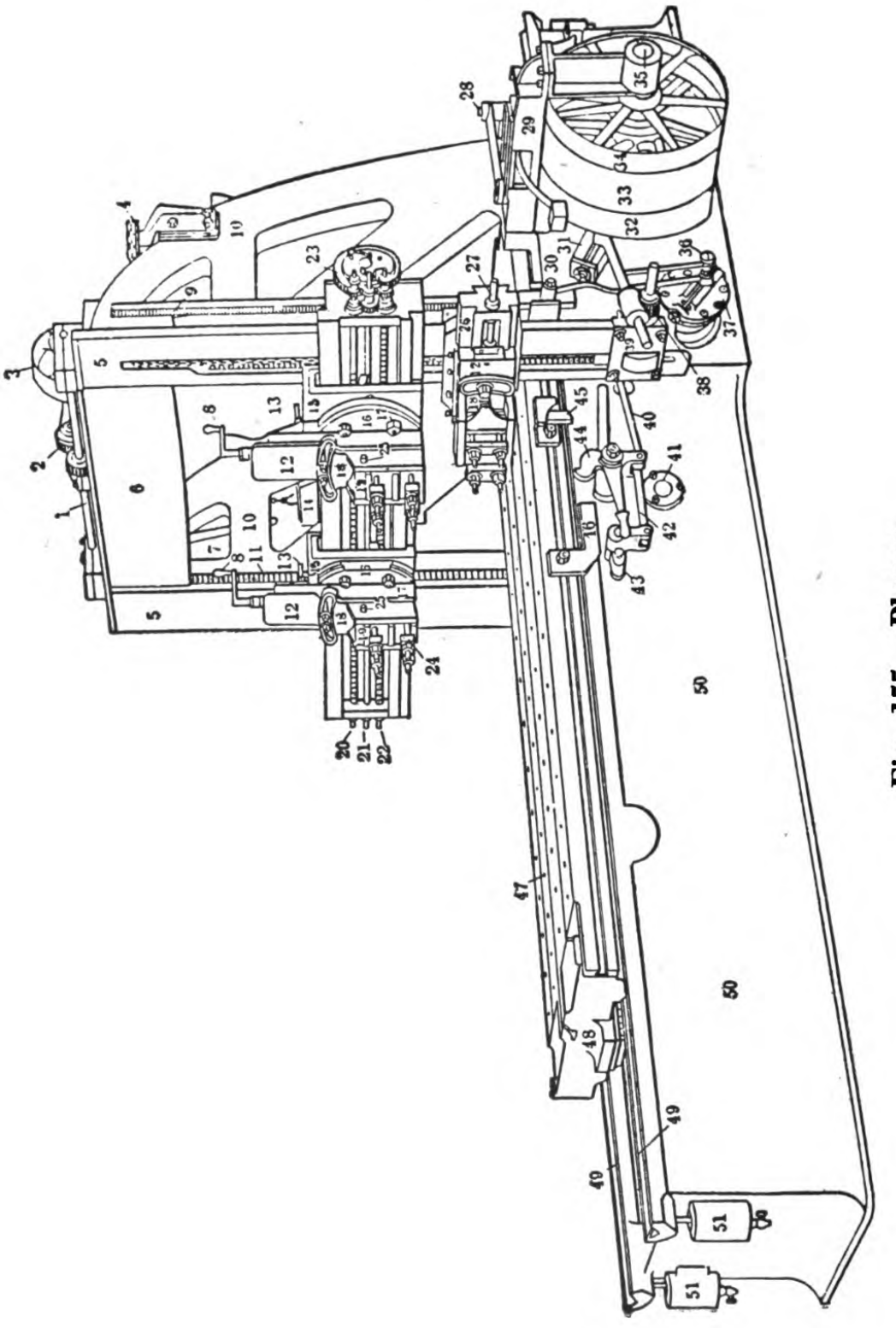


Fig. 155. Planer

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Parts of a Planer

1. Shaft for raising cross rail
2. Gears for raising cross rail
3. Pulley drive for raising cross rail
4. Chain for counterweighting the cross rail
5. Face of uprights
6. Tie piece between uprights
7. Handle controlling cross rail raising mechanism
8. Crank handle for raising tool block
9. Rack for moving feed screw in cross rail
10. Upright or housing
11. Screw for elevating cross rail
12. Tool slide
13. Saddle clamp
14. Counterweight for left side of cross rail
15. Tool block saddle
16. Tool block swivel
17. Swivel clamping bolt
18. Clapper box
19. Clapper block
20. Feed screw for left-hand head
21. Vertical feed rod
22. Feed screw for right-hand head
23. Feed mechanism on end of cross rail
24. Tool holder
25. Clapper block pin
26. Side head
27. Side head feed screw
28. Belt shifter
29. Driving pulley support
30. Connection to feed rack
31. Regulator for vertical feed
32. Forward driving pulley
33. Loose pulley
34. Return driving pulley
35. Driving shaft
36. Cross feed regulator
37. Cross feed drive
38. Vertical feed pinion
39. Vertical feed screw
40. Rod to belt shifter for reversing
41. Bull or driving gear shaft
42. Connections to safety lock
43. Lock to prevent table being moved
44. Reversing latch or trip
45. Forward stop dog
46. Backward stop dog
47. Platen or table
48. Rack under platen
49. Ways or V's
50. Bed
51. Oil reservoirs

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calls for a 70° angle from the horizontal, the head should be set at 20°. If an angle of 60° from the vertical is desired, the head should be set at 60°. Some planer heads are graduated

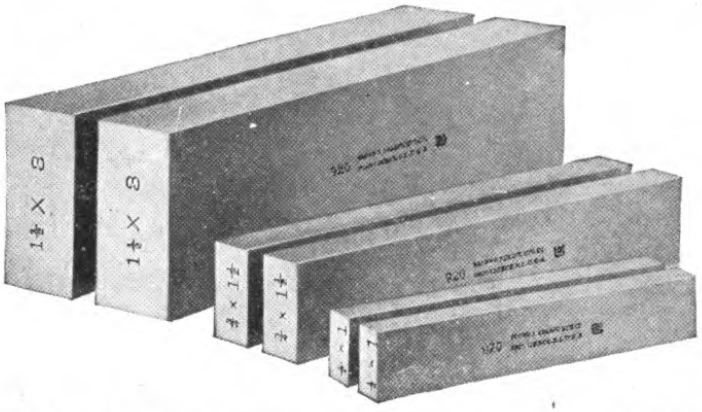


Fig. 156. Hardened and Ground Steel Parallels

to read from the horizontal. In such a case the zero line and 90° graduation coincide when the swivel slide is set vertically. To set the head at an angle, reverse the above procedure.

Parallels. — In leveling work on a planer table parallels are frequently necessary. They may be of cast iron or steel. Those shown in the illustration, Fig. 156, are of steel, hardened and ground. They are made straight and true and are interchangeable.

Holding Work. — A planer that is required to handle a variety of work should be equipped with a complete assortment of work holding accessories such as iron clamps and bolts, leveling jacks, step blocking, T bolts, nuts and washers, screw pins, screw bunters, fingers and toe dogs.

Before placing a piece of work on the table or in a fixture be sure that all bearing points are free from dirt and chips. See that the work is well supported, particularly long and heavy work, so that it will not sag and thus cause finished surfaces to be out of line when the piece is removed from the table. In clamping work be sure that the T bolt that passes through the clamp is placed nearer to the work than to the blocking. The clamp should be placed squarely across to give a full bearing at each end. In this position it will exert the greatest pressure on

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the work and will require the least effort to set up the nuts. After clamping the straps lightly, tap the work down on all bearing points to insure a firm bearing, and then tighten the clamps.

When the work is clamped to the table it is a problem to clamp it firmly without springing it and so that accurate planing can be done. The work must be firmly clamped or it may move during the cut and thus throw the surfaces out of alignment. On the other hand, if the work should be clamped in such a careless manner as to spring the parts, the finished surfaces will be out of true when the work is released. Never clamp over a part of the work that does not have a firm bearing on the table. Use blocks, shims, and strips of tin freely so that no part of the work will rock on the table before the clamps are applied.

It is a good plan to take all the roughing cuts before a finishing cut is started. Loosen the clamps and holding devices slightly after roughing. The reason for this is that where the " skin " of a casting is removed certain internal stresses are produced to an extent that may leave the work in a distorted condition after the holding devices have been removed. By easing up on the clamps very slightly and then taking the finishing cut, this distortion can be corrected. Care should be taken to see that the work is braced with stops as well as held by clamps when planing. The clamps hold the work down on the table while the stops prevent it from sliding.

Planer Feeds. — It is difficult to state a definite rule for determining planer feeds as the working conditions vary in different shops. Proper feeds depend upon many conditions, the more important being: (1) kind of material; (2) depth of cut; (3) kind of tool; and (4) surface speed of table. Generally speaking, use the coarsest feed possible consistent with the capacities of the machine and the desired finish. The choice of the proper feed is best obtained from experience.

Planer Speeds. — In general we may conclude that the cutting speed of a planer should not be high enough to overheat the tool. We should take into account the quality of the metal being cut.

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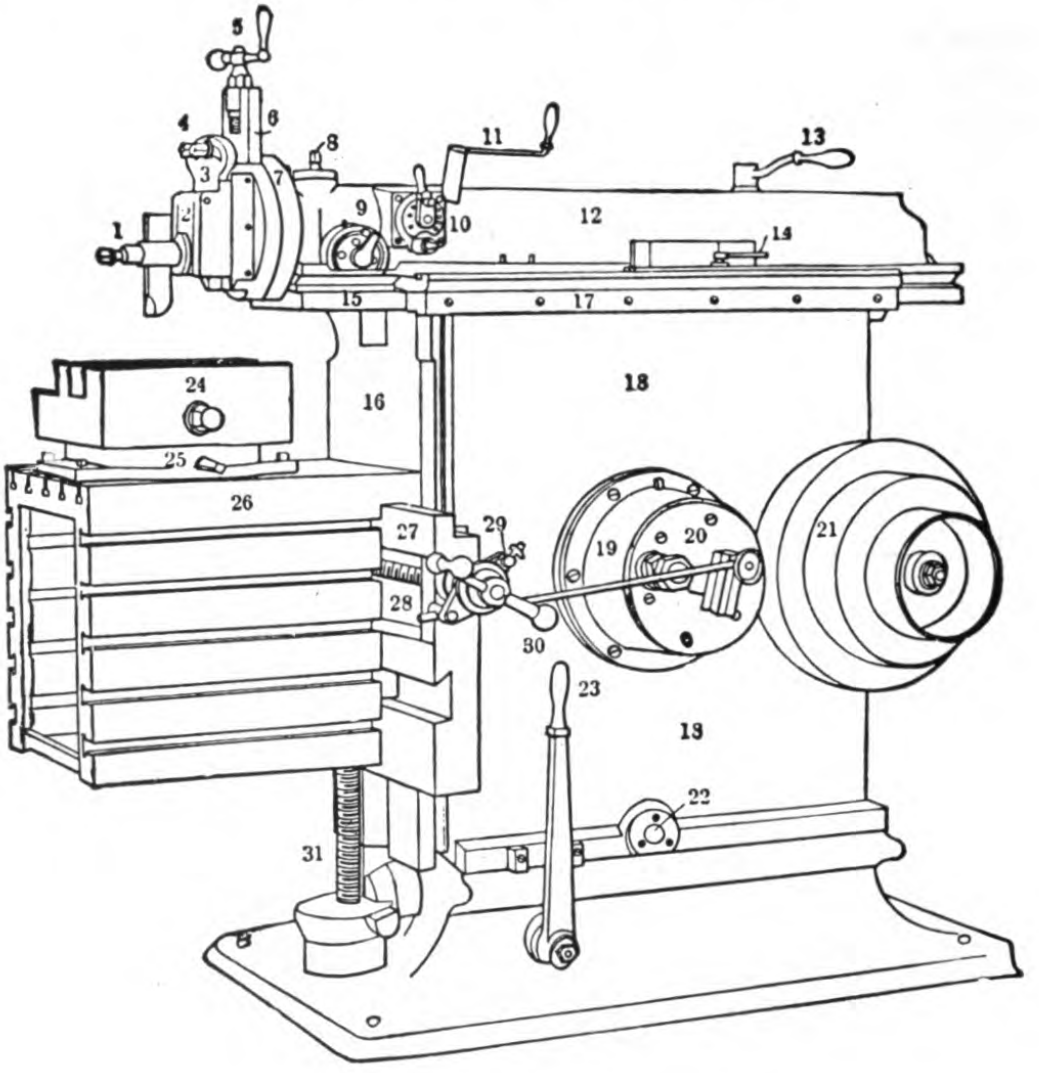


Fig. 157. Parts of a Shaper

1. Tool post
2. Clapper block
3. Clapper box
4. Clamping bolts
5. Down feed screw
6. Tool slide
7. Swiveling head
8. Clamp for head
9. Stop for down feed
10. Down feed regulator
11. Ram adjuster
12. Ram
13. Clamp for ram
14. Feed controller
15. Ram slide
16. Face of column
17. Ram guide
18. Frame or body
19. Feed box
20. Feed regulator
21. Cone driving pulley
22. Rocker bearing
23. Lever controlling power elevation of table
24. Vise
25. Swiveling vise base
26. Table
27. Table saddle
28. Cross feed screw
29. Cross feed pawl
30. Cross feed handle
31. Elevating screw

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Cast iron is usually rough planed at from 40 to 50 feet per minute; finished at from 20 to 25 F.P.M. Steel castings may be rough planed at from 30 to 35 F.P.M.; finished at 20 F. P.M. Wrought iron may be rough planed at from 30 to 45 F.P.M.; and finished at 20 F.P.M. Brass and bronze are usually planed at from 50 to 60 F.P.M. and machinery steel at from 30 to 35 F.P.M.

Rule: To find the cutting speed in feet per minute of a planer, divide the length of the stroke of the table *in feet*, by the number of seconds required to make the stroke, and multiply the result by 60. Thus: —

$$\text{Cutting Speed in feet per minute} = \frac{\text{stroke of table in feet}}{\text{seconds required for stroke}} \times 60$$

Shapers. — These machines, Fig. 157, accomplish work similar to that done on planers, although the construction of shapers is considerably different. On shapers the work is held on a table or knee, and the tool, held in a tool post on the reciprocating ram, moves across the work. The knee has both transverse and vertical adjustments, and is provided with hand and power feeds. These machines are particularly adapted to small work of the kind usually held in vises.

The crank shaper and the geared shaper are the two most common types. A crank movement for driving the ram, giving it a quick return, features the crank shaper. In the geared shaper the movement of the ram is obtained by a spur gear meshing with a rack fastened to the bottom of the ram.

The length of the ram stroke is adjustable. Work can be readily shaped close to a shoulder, as the length of stroke of the ram is positive.

Some types of shapers are equipped with a swiveling table or knee. This allows the top of the table to be set at an angle, permitting the shaping of angular work with great facility.

The grinding of shaper tools, the feeds and speeds used and the holding of work, with the exception of using a vise, are all similar to planing. A knowledge of the use of a planer will readily permit one to operate a shaper.

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CHAPTER VII

Milling and Milling Cutters

Milling is a mechanical operation whereby work is machined by means of a rotary cutter to regular or irregular shapes.

The existing types of milling machines are very numerous and their designs merge into one another to a great extent. However, the most common are the column and knee (including vertical spindle), manufacturing, automatic, duplex, planer and drum types, together with special and single purpose machines. A new development is a milling machine whose table feed, speed, spindle movements, and other operations are electrically controlled.

We shall not attempt to describe any but the column and knee and manufacturing types as they are the most common and in general the same principles apply to all.

Column and Knee Milling Machines. — This type machine has a rigid column, in which is mounted the spindle, and a table supported by a vertically adjustable knee. Provision is made for horizontal movement of the table both parallel and at right angles to the axis of the spindle. The combination of the vertical, transverse, and longitudinal table movements is found only in the column and knee type machine, thus giving this type advantages on general milling work. Plain, universal, vertical spindle and some automatic machines are of this design.

Manufacturing Milling Machines. — This type is characterized by the fixed table height. Vertical adjustment is obtained by an adjustable spindle head and only slight transverse movement is provided. These machines are noteworthy for their rugged construction and ease with which they are operated. " Lincoln " type, duplex and some automatic milling machines come under this classification.

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A Brown & Sharpe Plain Milling Machine, Fig. 158, electrically controlled, is a recent development of a modern type of production milling machine of the manufacturing type. This machine has complete electrical control for all table feed, speed and spindle movements which aids in exceptional rapidity and precision. The unusual range of feeds and speeds available provides for a wide variety of work, and an automatic table reverse makes it possible to rough and finish mill at one chucking by using dual feed rates, if desired.

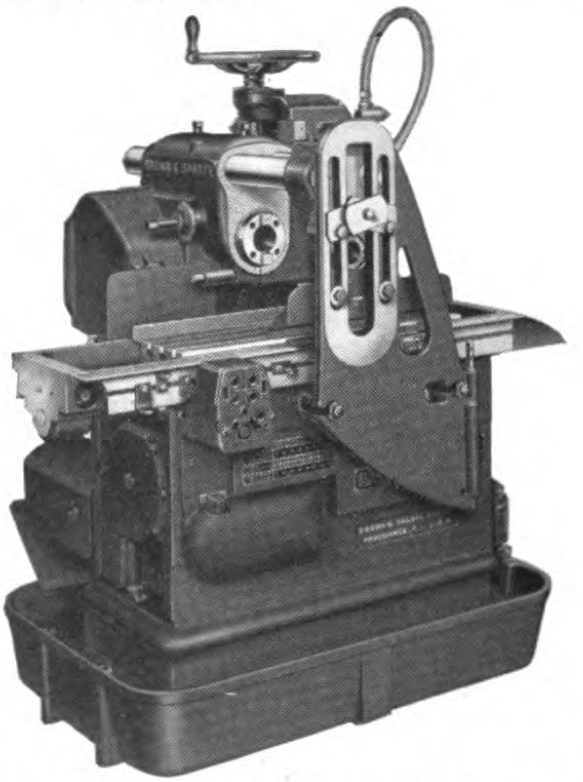


Fig. 158. An Electrically Controlled Manufacturing Type Plain Milling Machine

This machine is adapted for climb milling as well as conventional milling.

For further information on the subject of milling, we invite the reader to refer to the " Practical Treatise on Milling and Milling Machines," listed at the back of this book. This treatise deals with the art of milling and the operation of milling machines in a concise and practical manner.

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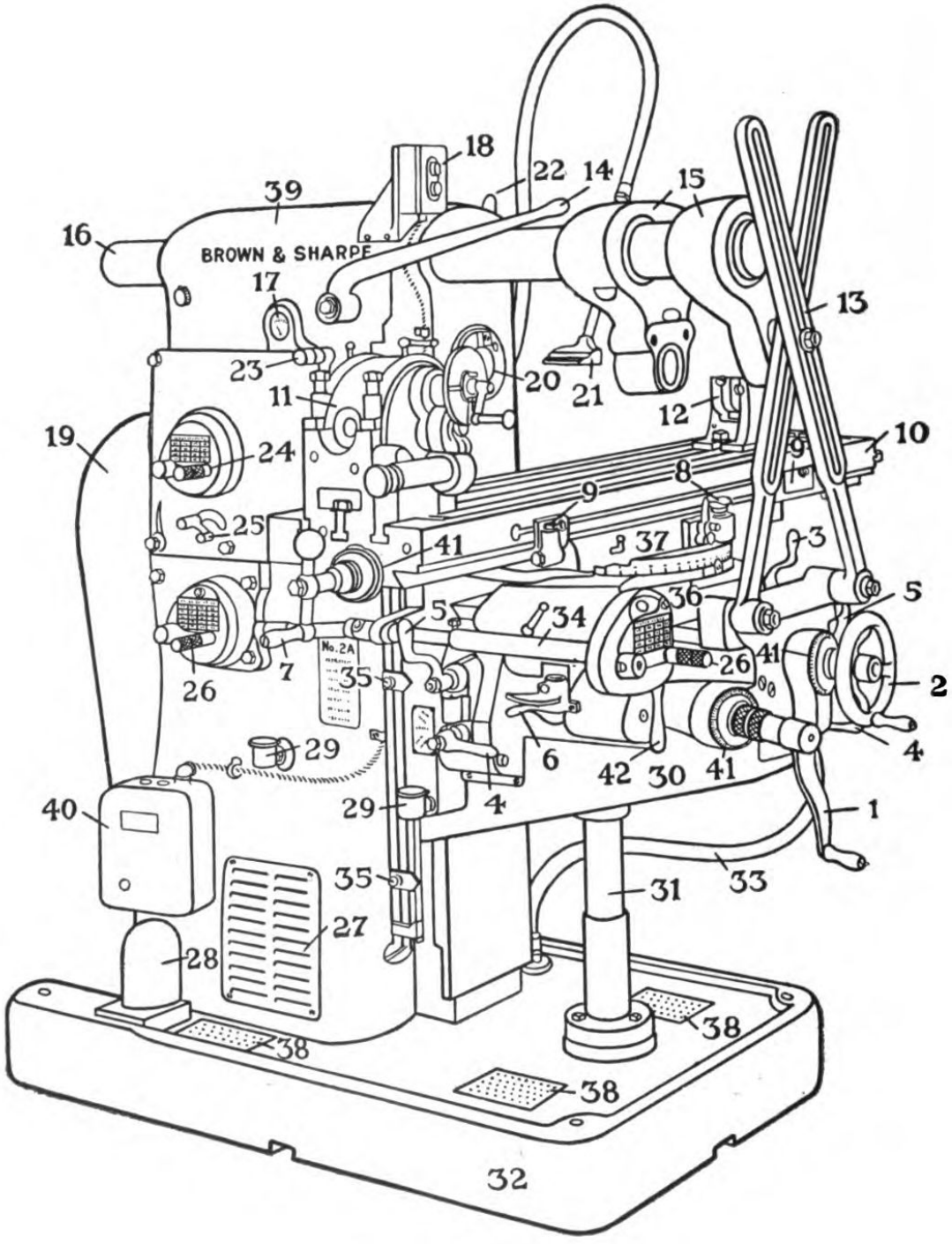


Fig. 159. A Motor Driven Universal Milling Machine. (Motor-in-the-Base Type)

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Parts of a Universal Milling Machine

1. Handcrank for vertical adjustment
2. Handwheel for transverse adjustment
3. Table power fast travel control lever
4. Power vertical feed control lever
5. Power transverse feed control lever
6. Lock for transverse and vertical feeds
7. Longitudinal table hand adjustment crank
8. Table longitudinal feed engagement lever
9. Adjustable table dogs with positive stop and trip combined
10. Table
11. Universal Spiral Index Centers
12. Footstock
13. Arm braces
14. Starting lever
15. Arbor yoke
16. Double overarm
17. Lubricating system pressure gage
18. Push button electrical motor control
19. Guard over silent driving chain from motor
20. Standardized Spindle End
21. Cutter coolant distributor nozzle
22. Overarm clamping lever
23. Spindle speed back gear lever
24. Spindle speed change lever
25. Spindle reverse lever
26. Feed change lever
27. Ventilator to motor compartment
28. Guard covering motor chain adjustments
29. Filling spouts for oil reservoirs
30. Knee
31. Knee elevating screw
32. Base
33. Flexible tube for return of cutter coolant
34. Feed change control shaft
35. Vertical feed trip dog
36. Clamp bed
37. Swivel
38. Strainers to cutter coolant reservoir
39. Column
40. Electrical control for motor
41. Adjustable dials for hand adjustment
42. Knee clamp lever

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Kinds of Milling Cutters. — There is a wide variety of styles of milling cutters available to meet the diversified requirements of milling machine work. They are made of either carbon steel or high speed steel, but the latter, because of its greater durability, is in more general use in spite of the higher first cost. The larger sizes of milling cutters are made with a machine steel or cast iron body and with inserted teeth of high speed steel.

Tungsten Carbide. — Tungsten Carbide is a relatively new cutting tool material composed of tungsten, carbon and cobalt. It is very expensive and generally is used in the form of rectangular tips brazed to steel shanks which become the teeth of inserted tooth face milling cutters.

Tungsten Carbide is used, also, for tipping the teeth of certain types of solid cutters where the diameter of the cutter makes inserted tooth design impractical.

As it is comparatively brittle, the cutting edges of cutters must be backed up in the best possible manner.

Cutters with Tungsten Carbide tips are used mostly on cast iron and on non-ferrous materials. Under favorable conditions such cutters can be operated at higher speeds than cutters of high speed steel. See also page 256.

The addition of tantalum or titanium to tungsten carbide aids in avoiding excessive cratering or the building up of material by the cutter and high frictional heat that may occur.

Tungsten Carbide cannot be machined except by grinding due to its extreme hardness and the use of special grinding wheels is recommended for sharpening.

Stellite. — Stellite is a non-ferrous alloy of varying percentages of chromium, cobalt and either molybdenum or tungsten. It cannot be forged or machined except by grinding, but can be cast readily. Cutters with cutting edges of this material retain their cutting quality at high temperature, and can be used at higher peripheral speeds than cutters of high speed steels.

Small cutters made of Stellite, are usually solid, while on larger cutters the teeth are clamped to a steel disk.

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Cutters with Stellite teeth are used satisfactorily for mass production such as for milling automobile engine castings and similar parts.

Advantages of Coarse-Tooth Milling Cutters. — In the development of coarse-tooth milling cutters the aim has been to obtain the freest possible cutting action without lessening the accuracy of the work. They are capable of removing a considerably greater quantity of metal in a given time without distressing the cutter or overloading the machine.

The wide spaces between the teeth also allow the cutting edges to be well backed up, which was not always possible with closely spaced teeth. Therefore, the cutters are well prepared to handle deep and rapid cuts without danger of failing.

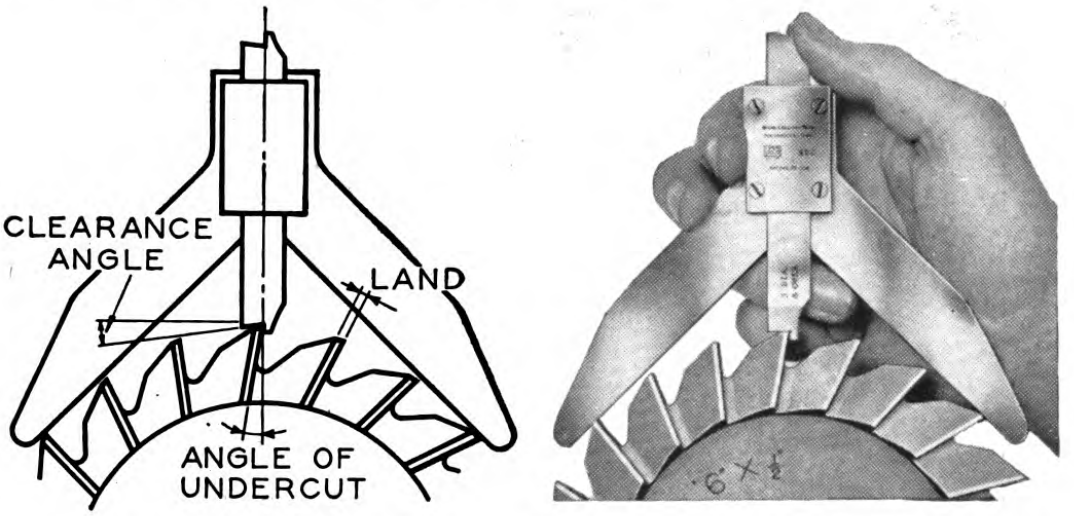


Fig. 160. Checking Clearance with Cutter Clearance Gage

Of course, the amount of improvement in these points varies greatly on different jobs, owing to the particular conditions, such as the stiffness of the work, nature of the cut and strength of the machine.

Clearance on Cutters. — When sharpening cutters, the clearance should always be taken into consideration, Fig. 160. Clearance, or relief, on milling cutters is the amount of material removed from the top of the teeth back of the cutting edge, to permit the teeth to clear the stock and not scrape over it after

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the cutting edge has done its work. On formed and gear cutters, clearance does not have to be considered in resharpening, because the teeth are so formed that when ground radially on the faces the clearance remains the same.

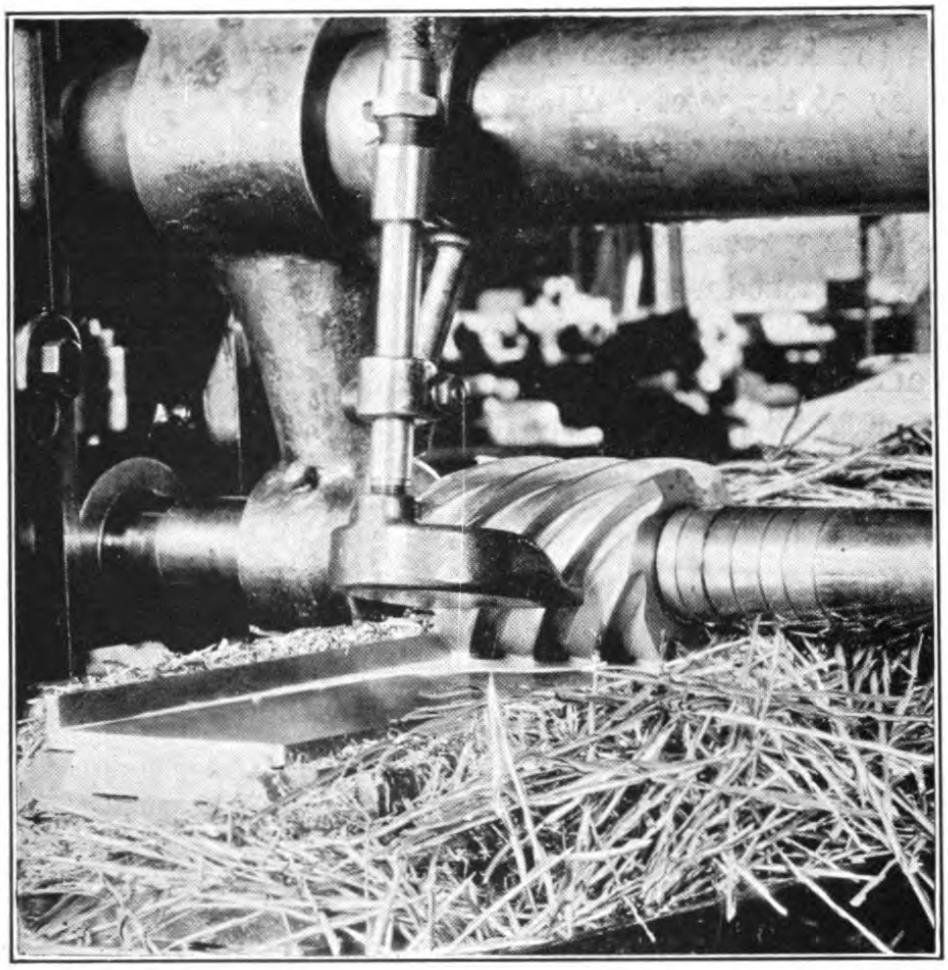


Fig. 161. A Helical Milling Cutter in Operation

The angle of clearance depends upon the diameter of the cutters and must be greater for small cutters than for large ones. The clearance on the teeth of plain milling cutters should be 4 degrees for cutters over 3 inches in diameter, and 6 degrees for those under 3 inches, and the land at the top of the teeth should be from .03 to .05-inch wide before the clearance is ground. In the case of the smaller end mills and other cutters of similar diameters an increase above the 6° angle will frequently

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be necessary to insure the back corner of the sharpened land being lower than the cutting edge. The clearance of the end teeth of end mills should be about 4 degrees, and it is well to have the teeth a little hollowing, letting them be .001 or .002-inch lower near the center than at the outside, so that the inner ends of the teeth will not drag on the work. This can be done by setting the swivel on the cutter grinding machine slightly away from 90 degrees. If the clearance of a cutter is too great, vibrations are likely to occur in operation and the cutter may not stand up.

Plain Milling Cutter. — The plain milling cutter, Fig. 162, is used to machine flat surfaces. Although the action of the

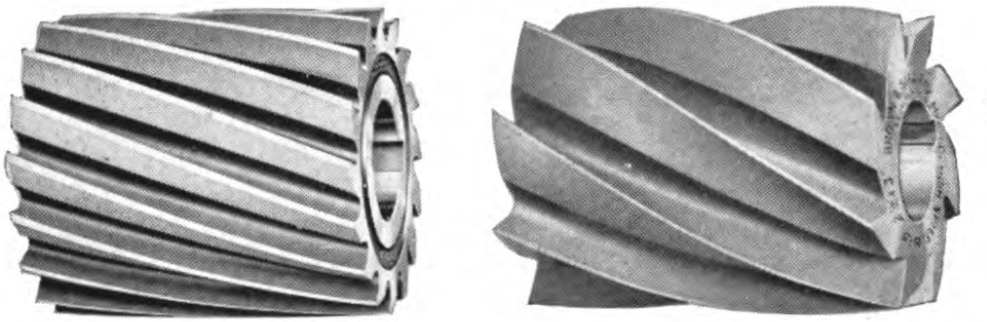


Fig. 162. Plain and Coarse-Tooth Milling Cutters

screw slotting cutter and slitting saw is very similar to that of the plain milling cutter, yet the true plain milling cutter has a face much wider in proportion to its diameter than either of the former. The teeth of plain milling cutters greater than 3/4" in width are cut spirally. The spiral shaped tooth makes cutting easier and reduces the tendency to spring the arbor. A part of some tooth should always be in contact with the work, to give a more uniform cutting action.

Side Milling Cutter. — It is used essentially to cut surfaces at right angles to the axis of the cutter. As shown in Fig. 163, it has teeth on both sides and on the periphery. Side milling cutters are often used in pairs for sizing nuts, bolt heads and similar work and, when so mounted together with a space be-

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tween, are known as straddle milling cutters or more commonly as " straddle mills."

Angular Cutter. — As its name suggests, Fig. 164, this cutter is used to mill surfaces that are to be cut at an angle with

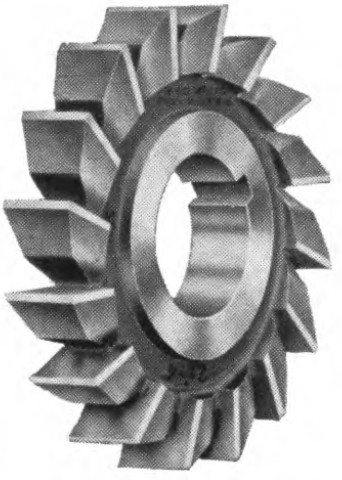


Fig. 163. Side Milling Cutter

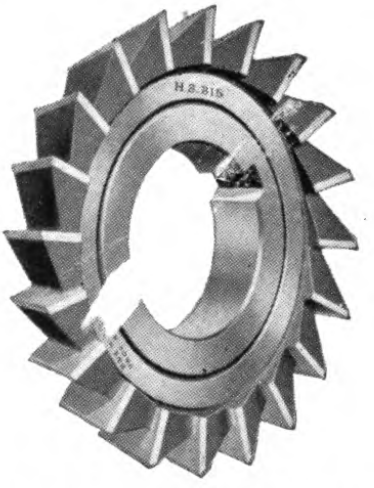


Fig. 164. Angular Cutter

the axis of the cutter, such as for cutting the teeth of cutters and mills. Stock cutters usually have angles of 45° or 60°, and are made either right- or left-hand. Double angle cutters are also available; the stock sizes have a 45°, 60°, or 90° included angle.

Staggered Tooth Side Milling Cutter. — Because of the alternate right- and left-hand spiral angles of the teeth, Fig. 165, with considerable angle of undercut, this cutter can remove a large amount of metal without destructive vibration and chatter, taking deep cuts and leaving a good finish. The free cutting action makes possible an increased speed and feed. Cuts can be taken easily that would stall an ordinary cutter. While intended primarily for deep cuts in steel, staggered tooth side milling cutters will operate on shallow cuts. This is an advantage if the work requires cuts of varying depths.

Half Side Milling Cutter. — While this side milling cutter, Fig. 166, has been developed for all side cuts where one side only

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is needed, such as in finishing bosses, it can be used equally well in pairs for cutting slots where a definite width must be main-

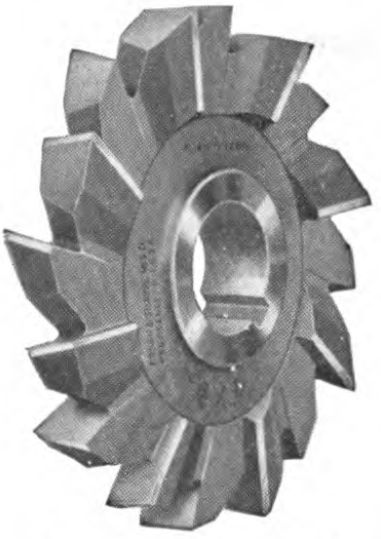


Fig. 165. Staggered Tooth Side Milling Cutter

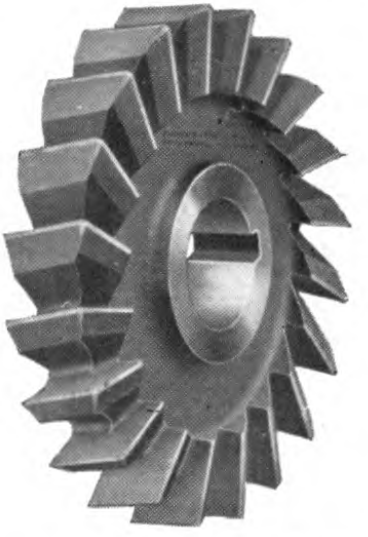


Fig. 166. Half Side Milling Cutter

tained, and where bottom finishing is not required. In Fig. 166 note the spiral on the top and undercut on the side, which tend to give the teeth an improved cutting action.



Fig. 167. Interlocking Side Milling Cutter

Interlocking Side Milling Cutter. — Cutters are sometimes made, as shown in Fig. 167, of the Interlocking type. In addition to having the advantage of the half side milling cutters, i.e., efficient cutting action because of the spiral angle and undercut teeth, the interlocking side milling cutters have the added advantage of being suitable to finish the bottom of slots, while having adjustment for holding the slot to a required width.

Helical Plain Milling Cutter. — This modern type of cutter, Fig. 168, is especially efficient in taking heavy cuts and in producing a fine finish without chatter. It can be used to

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particular advantage in removing an uneven amount of stock without gouging, and is made in hole and arbor types.

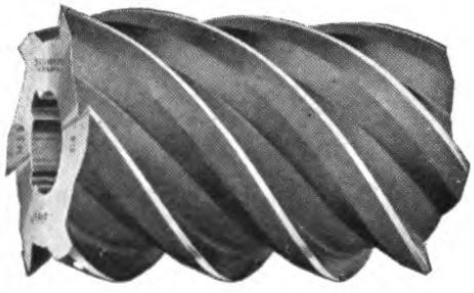


Fig. 168. Helical Plain Milling Cutter

Internal finishing, working either from a drilled hole or directly in from the end of the piece, is the kind of work for which the arbor type helical milling cutter is especially intended. The steep spiral gives the milling cutter a shearing action that enables the cut to be taken easily while leaving a good finish. The undercut teeth contribute to the free cutting action.

Inserted Tooth Milling Cutter. — Milling cutters larger than 8″ in diameter are usually made with inserted teeth, Fig. 169. The teeth are inserted in slots around the periphery of a machinery steel body. They may be of either carbon or high speed steel, and sometimes stellite blades are used or blades with tungsten carbide tips. The larger sizes of side and face milling cutters are usually made with inserted teeth.

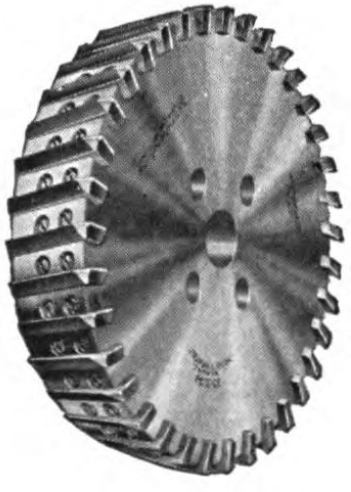


Fig. 169. Inserted Tooth Face Milling Cutter

Formed Milling Cutter. — This type of cutter, Fig. 170, is used to cut curved or irregular surfaces. Such cutters are used to a great extent for fluting taps, reamers, twist drills and to cut sprockets and gear teeth. They should be sharpened radially on the face of the teeth. Sharpened in this way the form will never vary and the clearance will always be the same. This is due to the eccentric relief back of the point of each tooth.

Form Milling Cutter. — It might be well to get the distinction clearly in mind between form*ed* cutters and *form* cutters,

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Figs. 170 and 171. The form*ed* cutter has just been discussed; the *form* cutter is made like other milling cutters and is sharpened by grinding the tops of the teeth while the outline of the teeth corresponds to the required form.

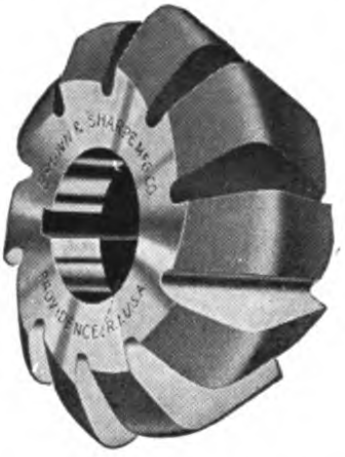


Fig. 170. Formed Milling Cutter



Fig. 171. Form Milling Cutter

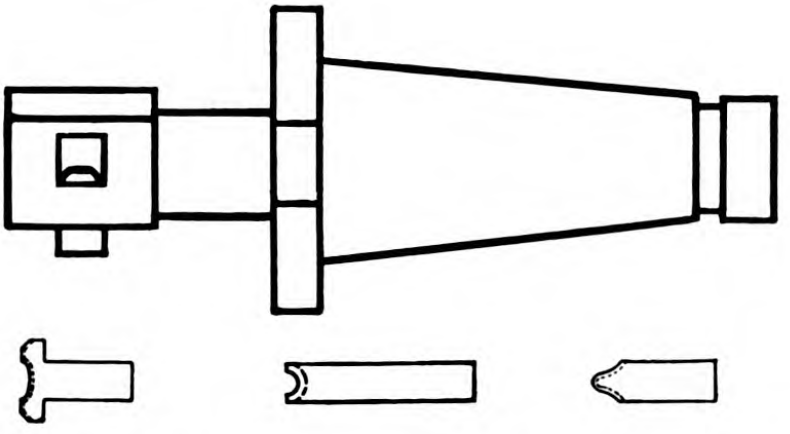


Fig. 172. A Fly Cutter Arbor with three cutters

Fly Cutter. — This is essentially an improvised cutter, Fig. 172. In reality it is comparable to one tooth of a form cutter used with a very fine feed. The fly cutter or fly tool is usually hand formed and used for one or only a few pieces. The advantages of a fly cutter are the ease with which it can be formed and the economy of its construction. It is made to the required

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shape, with the proper cutting clearance and then hardened, tempered, and sharpened on the face.

End Mill. — An end mill is a cutter with teeth at the end as well as on the face, Fig. 173. A common style is made with a Brown & Sharpe taper shank and a tang to fit the tapered hole in the collet or machine spindle. Straight shank end mills and end mills with Morse taper shanks are also available in many sizes as well as end mills having a Milling Machine Standard Taper

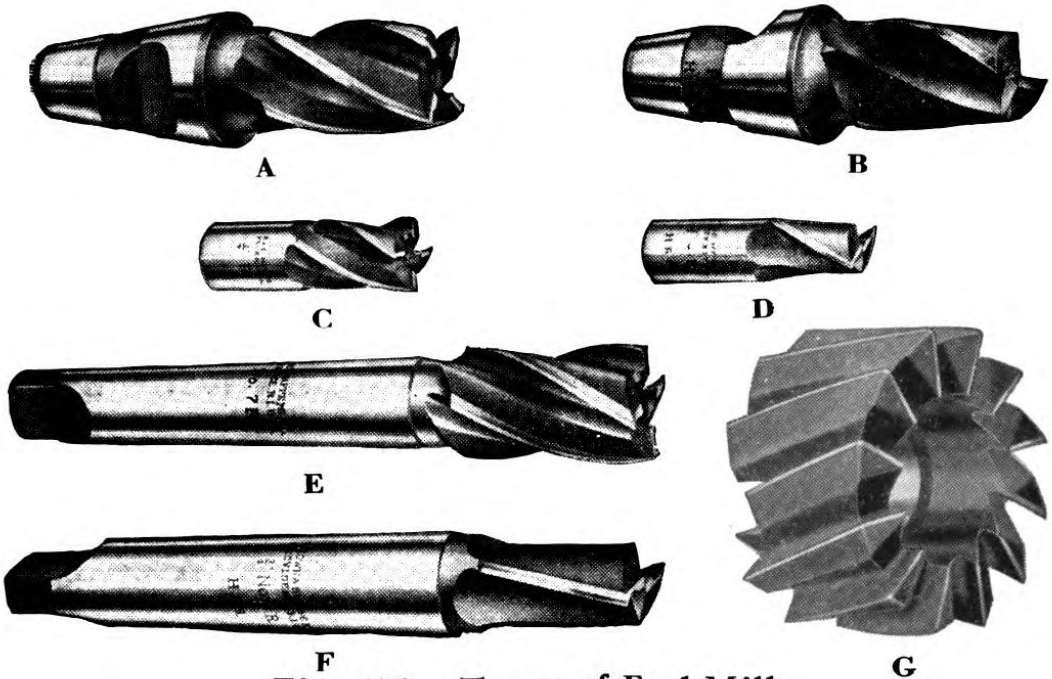


Fig. 173. Types of End Mills

A — Spiral End Mill, Milling Machine Standard Taper Shank, for use with Cutter Adapter with Cam Lock

B — Two Lipped Spiral End Mill, Milling Machine Standard Taper Shank, for use with Cutter Adapter with Cam Lock

C — Spiral End Mill, Straight Shank

D — Two Lipped Spiral End Mill, Straight Shank

E — Spiral End Mill, Brown & Sharpe Taper Shank

F — Two Lipped Spiral End Mill, Small Helix Angle, Brown & Sharpe Taper Shank

G — Shell End Mill for use with Shell End Mill Arbor

Shank with groove for Cam Lock, Fig. 178. End mills are designed to do most of the cutting on the end, at right angles to the axis of the cutter. Shell end mills have a hole and are used on special arbors, Fig. 179.

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Two Lipped End Mill. — This type of end mill, see Fig. 173, is especially useful for milling slots from the solid metal, where previously it was necessary to drill holes and make several cuts before completing the slot. It should be run at high speed and a maximum depth of cut equal to one half the diameter of the mill can usually be taken from the solid stock.

T Slot Cutter. — This tool is used chiefly for milling T slots and it is really a small staggered tooth milling cutter carried on a shank, Fig. 174. It cuts at right angles to its axis.



Fig. 174. T Slot Cutter

Saws. — Metal slitting saws, Fig. 175, are in reality thin milling cutters. They are ground on the sides, and are left a little thicker at the outer edge than near the center in order to give a proper clearance for cutting deep slots. Some saws have

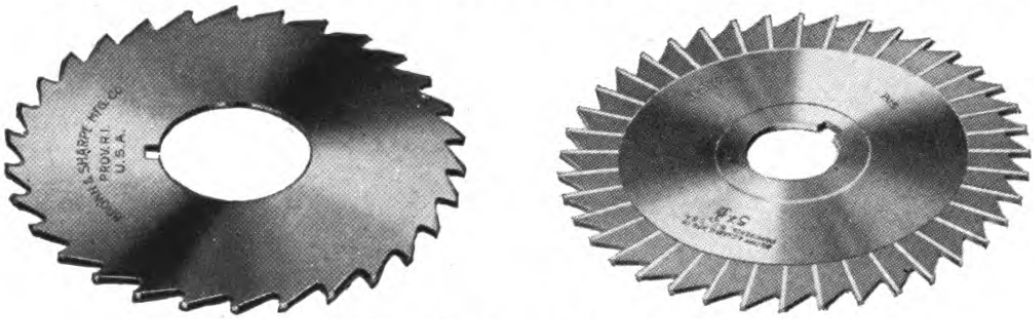


Fig. 175. Metal Slitting Saws

teeth made with side chip clearance in order to break up the chips and eliminate dragging. Saws for slitting copper and soft metals are either of the milling cutter type with opposite corners of alternate teeth chamfered or the formed type where each alternate tooth is V shaped, the point of the V extending beyond the cutting edges of the straight teeth.

Arbors for Milling Cutters. —Figure 176 shows some milling cutter arbors. They are provided with a taper shank on one end to fit the taper hole in the milling machine spindle. The projecting part of the arbor is cylindrical in shape to fit the holes

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in the cutters. Steel collars of varying thicknesses are also provided, and a nut at the end tightens the collars against the cutter.

Arbors for heavier work are provided with bearings for arbor

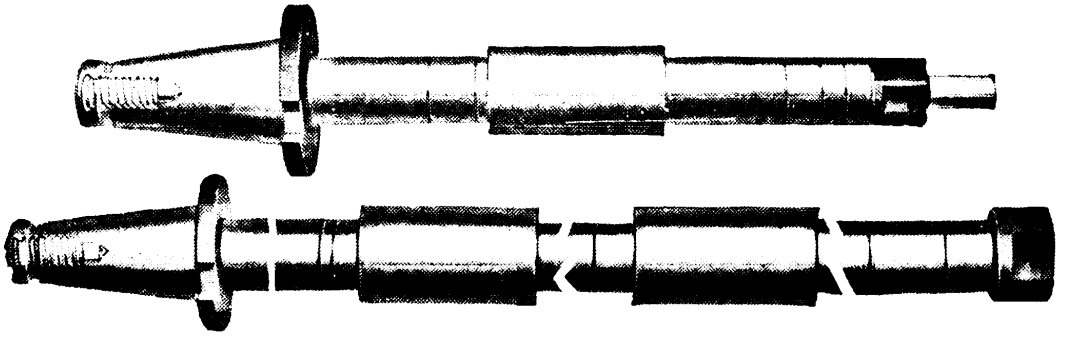


Fig. 176. Milling Cutter Arbors

yokes, and on some sizes there is also a smaller bearing that projects beyond the nut. On light work a cutter is prevented from turning on its arbor by the binding nut on the end of the arbor. A key is furnished for the keyway in the arbor and this should be used at all times.

An arbor may be removed by driving it out from the rear by means of a rod through the hole in the spindle. For heavier work the arbor is usually drawn into the tapered hole of the spindle by a draw-in bolt that passes through the hole in the spindle from the rear. The threaded end of the draw-in bolt engages a threaded hole in the tapered shank of the arbor and is removed by loosening the draw-in bolt and striking the end of the bolt with a hammer. Never strike the end of the draw-in bolt when it is entirely removed from the threads in the shank of the arbor as this will destroy the threads.

Complete interchangeability of all arbors and face milling cutters for any size or type of milling machine for 2 to 25 H.P. has been secured by the adoption of the Standardized Spindle End and a complete set of standardized arbors by the Milling Machine Manufacturers of the National Machine Tool Builders' Association.

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Adapters. — Adapters, Fig. 177, are used on milling machines having a standardized spindle end to accommodate Arbors, End Mills and other Adapters having Brown & Sharpe Taper Shanks. Fig. 178 shows an adapter furnished with a cam lock, a patented device, providing quick insertion or removal of certain end mills,

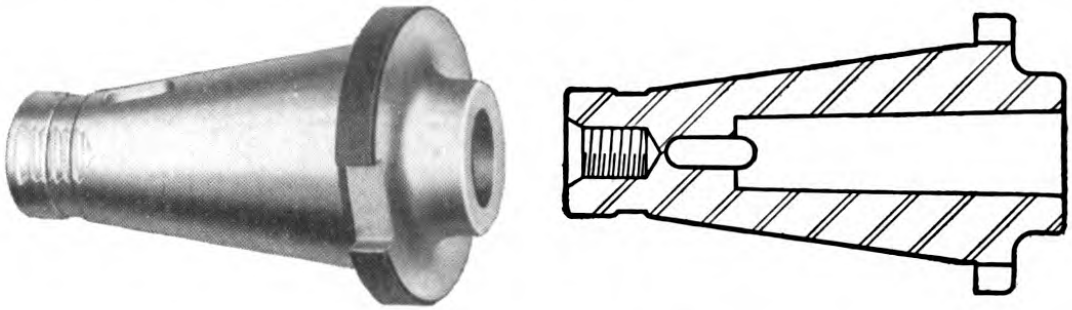


Fig. 177. An Adapter

adapters and arbors. Arbors and adapters for use with cam lock cutter adapters are shown in Fig. 179. The cutter adapter

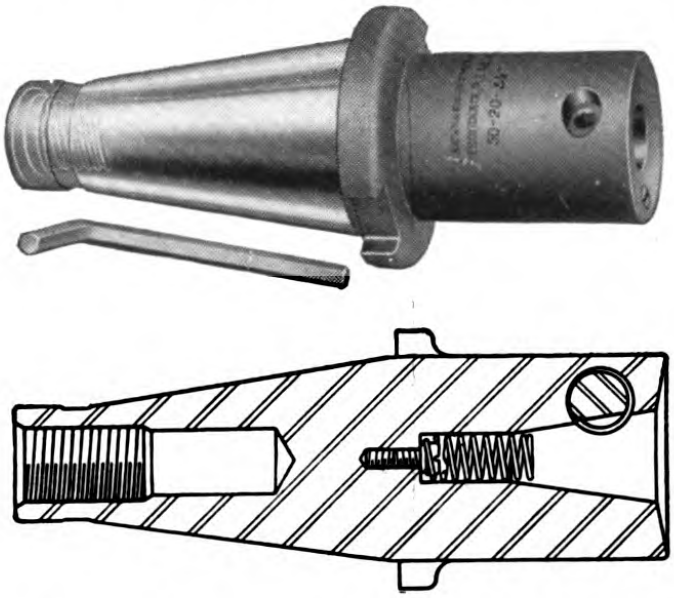


Fig. 178. A Brown & Sharpe Cutter Adapter with Cam Lock

bushings simplify the use of complete range of straight shank end mills in one adapter. End Mills for use with cutter adapters with cam lock are shown in Figs. 173A and 173B. As will

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be noted in the line illustration, Fig. 178, a locking cam engages a groove in the cutter or adapter shank and draws it securely to a seat. A slight turn with the wrench either locks or releases the shank. These adapters afford considerable saving in time in changing end mills and other cutters.

Cutting Speeds and Feeds. — It is impossible to state with

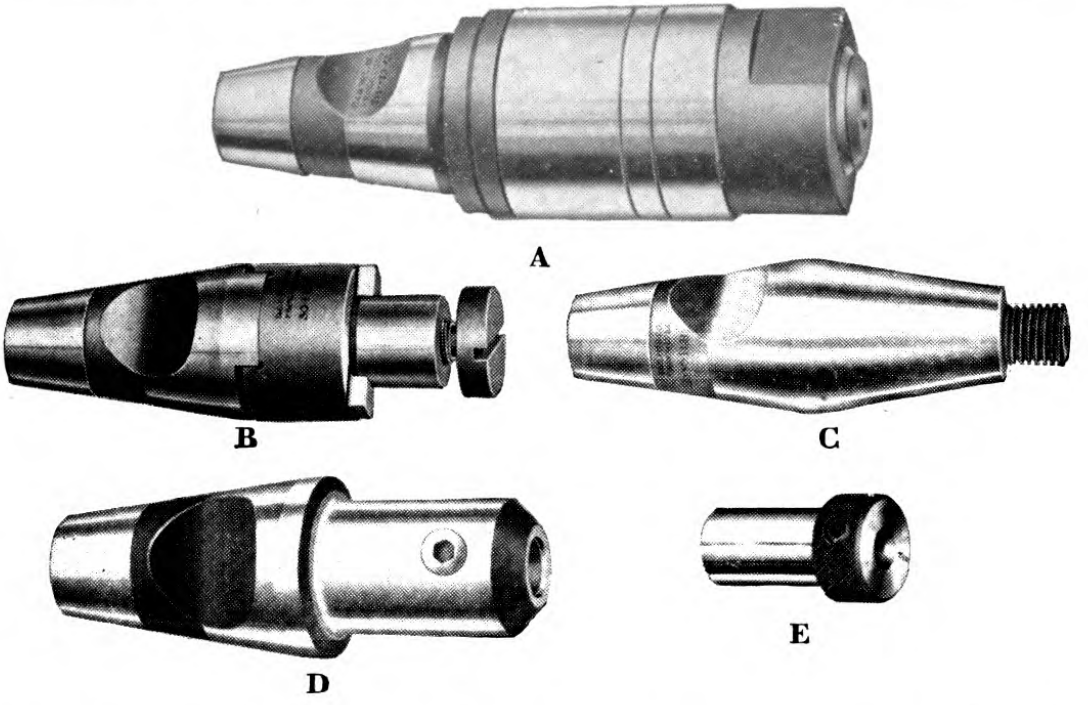


Fig. 179. Brown & Sharpe Arbors and Adapter for use with Cam Lock Cutter Adapters

A — Cam Lock Arbor
B — Arbor for Shell End Mill
C — Screw Arbor
D — Adapter for Straight Shank End Mill
E — Bushing for Straight Shank End Mill for use with Cutter Adapter

absolute accuracy the proper feed for a job. There are many factors to be considered, and no two jobs present the same problems. The best rule to follow in regard to speeds and feeds for milling as well as for other machines is to find out by trial what is the maximum with due regard for considerations of economy, accuracy and finish. For purposes of comparison, how-

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ever, it might be of interest to mention some relative speeds that have been found satisfactory under ordinary conditions.

The cutting speed of a milling cutter is expressed in feet per minute (F.P.M.) and can be determined easily as follows: Multiply 3.1416 by the diameter of the cutter, in inches. This, of course, gives the circumference of the cutter. Now multiply this figure by the number of revolutions of the cutter per minute and divide the result by 12 to get the answer in terms of feet.

Speeds. — Using carbon steel cutters, cast iron may be milled at 40 to 60 F.P.M.; machinery steel 30 to 40 F.P.M.; annealed tool steel at 20 to 30 F.P.M.; or brass, at 80 F.P.M. and up. Using high speed steel cutters, the following speeds are advocated: cast iron and machinery steel, at 80 to 100 F.P.M.; annealed tool steel, at 60 to 80 F.P.M.; or brass at 150 F.P.M. and up.

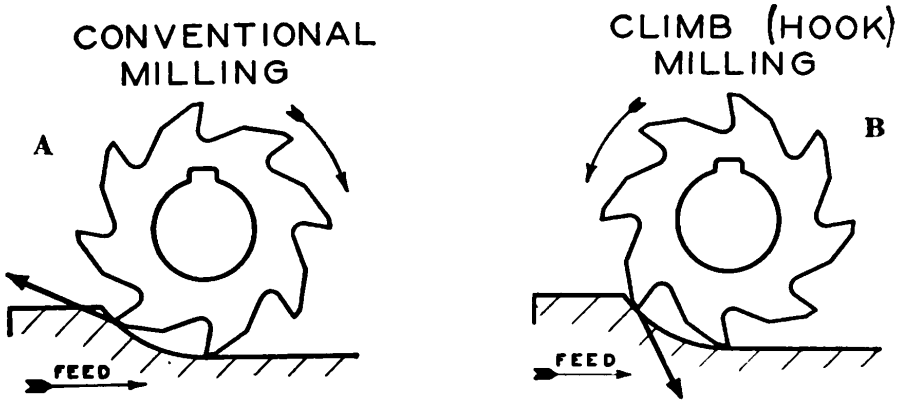


Fig. 180. Two Methods of Milling

Feeds. — The following considerations influence the rate of feed of a milling cutter: pitch of the teeth, amount of chip clearance, rigidity of the work and set up, power and rigidity of the machine, and the quality of finish required. Milling cutters have been fed from .002″ to .250″ per revolution of the cutter. Just which precise feed between these extremes would suit any particular case depends on the diameter of the cutter, kind of material of the work, width and depth of the cut, and the character and condition of the milling machine. Cutters are more likely to be

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ruined by not being kept sharp and by too high a speed than by coarse feeds. For the sake of economy remember this: keep your cutters sharp, and use a cutter with the smallest diameter practicable.

Conventional Milling. — In Conventional Milling, the direction of rotation of cutter is against the feed, Fig. 180A. The effect of backlash, which might cause the work to " draw in," is avoided.

Climb Milling. — Climb milling, Fig. 180, is not new but in the past it has been limited to very light cuts and was only possible on machines where the table gibs were made excessively tight or where machine tables were held back by heavy counterweights. Recently machines have been designed with sufficient rigidity and freedom from backlash to permit capacity climb milling cuts.

A typical machine employs a hardened and ground table screw and two screw nuts. A backlash-takeup mechanism forces the two nuts apart, removes all backlash and automatically takes up nut wear. To aid fast travel movements and to decrease wear the opposed nut pressure is automatically released whenever the table fast travel is engaged.

The forces shown by straight arrows in Fig. 180 give the clue to the first advantage of climb milling. The cutter, in B, tends to press the work down on the table when climb milling. In conventional milling the cutter, in A, has a tendency to lift the work from the table or vise. This downward pressure is very helpful in milling thin, narrow, delicate or irregularly shaped pieces which are difficult to hold.

On many jobs, cutters have been found to give a greater number of pieces per grind in climb milling than in regular milling.

It is easier to pull than to push a narrow saw through a cut. Better slots will usually be obtained if climb milling is adopted for saw cuts.

A machine capable of both climb and conventional milling is excellent for two fixture work. The cutter will climb mill the piece on one end of the table and conventional mill the piece on

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the opposite end. While the piece in one fixture is being milled the operator can be loading the other fixture. On any jobs where loading time is a fair portion of cutting time, such a two fixture setup will increase production.

With a climb milling machine it is often possible to take a finishing cut immediately after the roughing cut without removing the work from the vise. While the roughing cut is being made with climb milling the cutter and arbor spring a few thousandths. As soon as the roughing cut is completed, the table may be reversed in feed and the cutter will finish mill in the conventional manner removing the few thousandths left by the springing during the roughing cut.

The cutter tooth force in climb milling pulls the work toward the cutter. In conventional milling it is pushed away. It is thus very important to have end stops or clamps which will resist any tendency of the work or vise to slide on the table.

Lubrication for Milling Cutters. — Cast iron, bronze, and compositions are usually milled dry. On steel, cutting oils

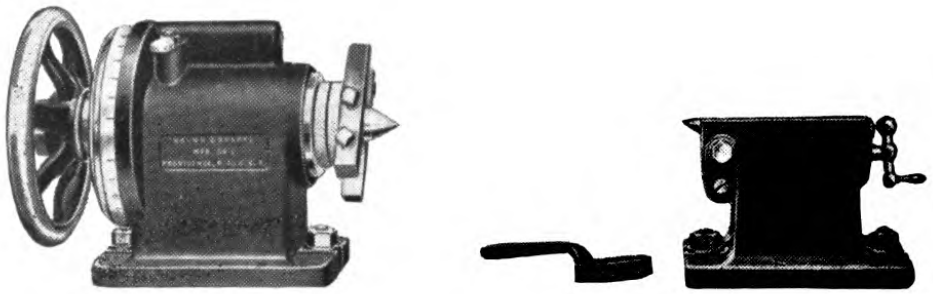


Fig. 181. Single Dial Index Centers for Rapid Indexing

and compounds are used. Soluble oils are used for their rust preventing qualities and the amount of oil present is dependent upon the degree of rust prevention desired. The cutting compounds are economical and have a high heat conductivity.

Sulphur base oils are used for a good finish, but on copper and brass they are apt to cause corrosion.

Lard oil has long been used as a cutting oil particularly for

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cutting threads and is still used in various percentages in many cutting oils.

Indexing. — Indexing is used to divide work accurately into a specified number of parts. We will discuss direct and plain indexing in as brief a manner as possible and, for a more detailed account and for differential indexing, reference to the " Practical Treatise on Milling and Milling Machines," listed in the back of the book is recommended.

Direct Indexing. — Figure 181 shows a set of single dial index centers for direct indexing. Index centers of this type are used only on work where a small number of divisions are required, as on nuts, bolt heads, and tap grooves. The method of holding the work between the centers is similar in every respect to that of the lathe; i.e., on centers, on a mandrel, or in a chuck. The index plate is fastened to the spindle and should have at least as many holes as the number of divisions required. A plate with a larger number of holes than required can be used if the number of holes is a multiple of the number of divisions desired. As an

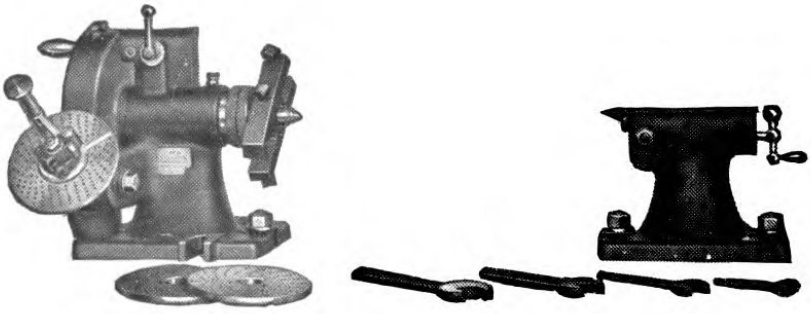


Fig. 182. Plain Index Centers

example a plate with 24 holes may be used to cut 24–12–8–6–4–3 or 2 divisions. If many pieces are to be cut, a plate with the exact number of holes is the safest, however, as there is then less danger of making mistakes in indexing.

A plate can be used for any number of divisions that will divide the number of holes in the plate evenly.

The number obtained by dividing the number of holes in the

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index plate by the number of divisions required represents the number of holes that the plate must be moved at each indexing or cut. For instance, suppose in the above case a hexagon bolt head is to be milled. There are, of course, 6 sides to a hexagon. The index plate in use has 24 holes. Therefore $24 \div 6 = 4$ and the plate must be moved 4 holes after each cut.

Plain Indexing.—Figure 182 shows a set of plain index centers which have the headstock spindle revolved by a worm wheel. The handle of the crank fastened to the worm shaft constitutes an index pin, and indexing is accomplished by means of a plate drilled with circles of different numbers of holes into which the spring pin of the crank fits. The worm wheel makes one complete revolution in 40 turns of the crank handle; therefore to determine the number of turns or part of a turn to make with the crank handle for each required division, divide 40 by the number of divisions in the work. In other words, where the number of divisions will divide into 40 with no remainder, use any hole in the circle and turn the crank twice for twenty divisions, four times for ten, five for eight.

When there is a remainder after dividing 40 by the required number of divisions, proceed as follows: Suppose there are to be 16 divisions. $40 \div 16 = 2\ 1/2$ times to revolve the handle. Use a plate on which there is a circle of holes that is exactly divisible by 2; for example a 16 hole circle. Drop the pin of the crank into a hole in this circle. An index sector consisting of two adjustable radial spacing arms is moved so that one of the arms of the sector is against the pin. Move the other arm of the sector so that it includes 8 spaces; 1/2 of 16 is 8. Tighten the sector clamping screw. There should always be one hole more between the arms of the sector than the number obtained in calculation or given in indexing tables. Indexing holes signify spaces.

Take the first cut, then make 2 turns with the crank and in addition the 8 spaces included between the arms of the sector.

Make the second cut. After the second cut, push the sector

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around until the other arm is in contact with the pin and rotate the crank 2 revolutions and 8 spaces as before. Proceed thus until the work is done.

Cams. — In Fig. 183, *A* is a cylindrical cam — sometimes called a barrel or drum cam. It has a groove cut about its periphery that can transmit motion by means of a roll and a

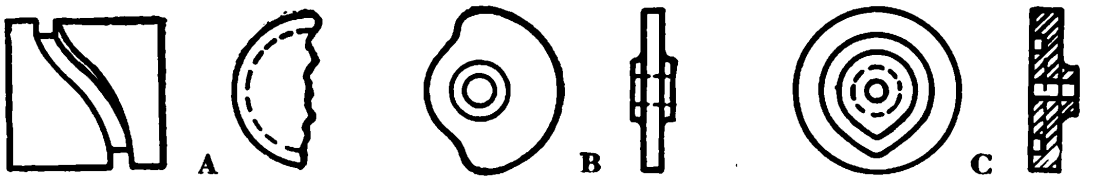


Fig. 183. Cylindrical Cam, Disk Cam, and Face Cam

lever in a plane parallel to its axis. This type of cam is sometimes built up by cam plates attached to a plain drum. *B* is a disk cam — sometimes called an edge cam. It can transmit motion in only one direction. Gravity or a spring may be used to keep the roll in contact with the edge of the cam. *C* is a face cam; because of the groove or path for a roll that is cut in its face it can transmit positive motion to a lever in any direction at right angles to its axis of rotation. The roll travels in and is guided by the sides of the groove that is cut in the face of the cam.

Cam Cutting Attachment.—Figure 184 shows a cam cutting attachment which is of advantage in the quantity production of cams having the same outline. Clamped to the table of a milling machine, it can be used for cutting face, cylindrical or peripheral cams from a flat former or disk cam. The necessary longitudinal and rotative movements are contained within the attachment, allowing the table of the machine to remain clamped in one position during the operation. The flat cam is made from a flat disk about 1/2″ thick and is secured to the face of the worm wheel on the spindle which carries the blank to be cut.

For cutting a cylindrical cam, the attachment head is bolted to the attachment bed parallel to the table and the cam blank is driven on an arbor mounted on the attachment centers. The

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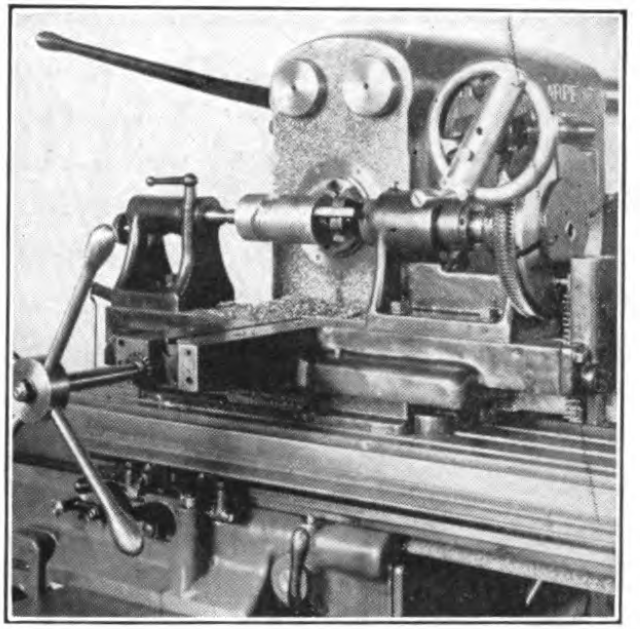


Fig. 184. Cutting a Cylindrical Cam, using Cam Cutting Attachment

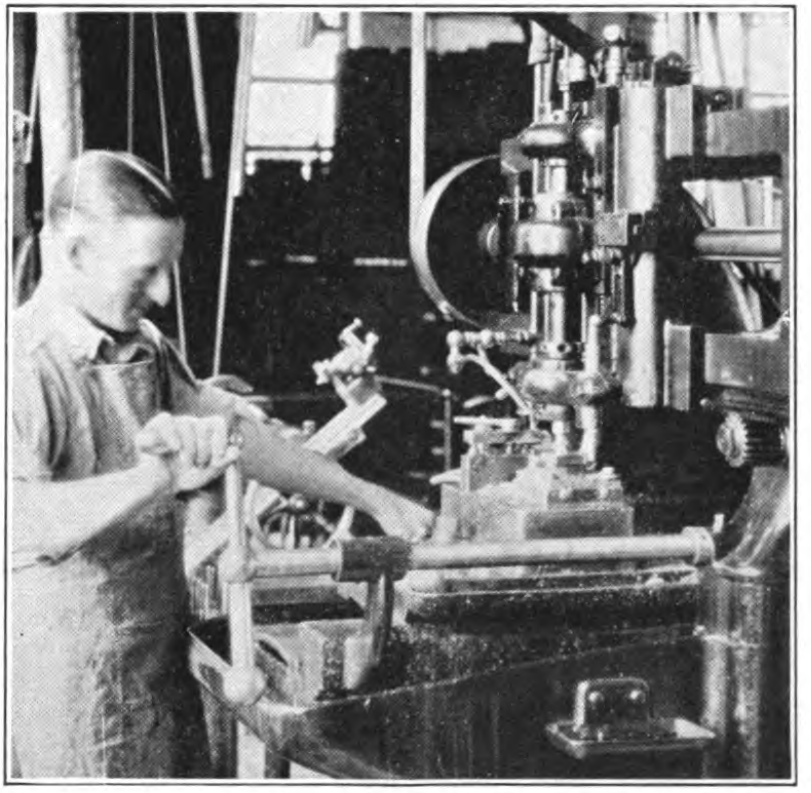


Fig. 185. Profiling Machine in Operation

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table is raised to a point that brings the attachment centers at the same height as the axis of the machine spindle.

A spiral end mill is used for the milling operation and the necessary movement to feed the work is obtained from the attachment, the table remaining clamped in one position.

Profiling. — This process is used in milling work to irregular shapes, using as guides hardened profiling forms that correspond to the desired shapes. The operation is similar to vertical milling except that automatic feeds are not used — the longitudinal and transverse feeds being directly under hand control of the operator and in use simultaneously.

The hardened form which is used to duplicate the required shape is attached to the machine so that both form and work have the same relative positions. An end mill is used in the spindle for a cutting tool and a hardened steel guide pin, the same size as the mill, is clamped in its holder parallel to the end mill and in contact with the outline of the form plate. A lever on the spindle head controls the vertical movement of the spindle, and a constant pressure downward is exerted on the spindle by the tension of a spring. In operation, the guide pin is held in contact with the outline of the form by a combination of the longitudinal and transverse hand feeds.

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CHAPTER VIII

Grinding

Grinding. — Grinding has developed considerably in the past 50 years and holds a very important place in manufacturing. From the beginning when natural sandstone was used for the grinding agent, to the present day when artificial grinding wheels are available, continued experiment has developed and determined the grinding tools best adapted for the many different metals and alloys so commonly used in manufacturing.

We find emery and corundum, two hard minerals, ready for use as abrasives in their natural states. These minerals were used as abrasives in early attempts to make artificial grinding wheels and were collected from many parts of the world. A variation in the quality, depending on the source of supply of these mineral abrasives, caused a corresponding variance in the quality and grade of the grinding wheels produced, with the result that artificial abrasives were experimented with.

Also, various bonding materials were investigated to obtain a more constant unchanging grade. Finally, development brought the use of aluminum oxide as an abrasive which, although subject to certain impurities, is very satisfactory. When melted, this produces a hard material similar to emery and corundum and which can be controlled for uniformity in production. Today, many grinding wheels are made with this abrasive.

Other wheels commonly used are those of silicon carbide which are composed of the raw materials, silica sand and carbon in the form of coke. These materials, subjected to the high temperatures of an electric furnace, react to form abrasive crystals. The crystals which are very hard and brittle are best for use in grinding materials of low tensile strength and for most non metallic substances.

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The present day use of tools and cutters tipped with the Tungsten Carbides (Carboloy, Firthite, Strauss Metal, and Widia) requires means of grinding and sharpening these extremely hard materials and has necessitated the development of special grinding wheels for this purpose.

In addition to a diamond wheel made of diamond grit held with bakelite bond, special silicon carbide wheels, unusually hard and sharp, have been developed with an open bond to give cool cutting qualities and long life when used on the Tungsten Carbides.

Bond

An important element in a grinding wheel is the bond, Fig. 186, which holds the abrasive particles together. It may be one of several different types as vitrified, silicate, elastic, rubber and resin. The bond is not an abrasive but a matrix that supports the abrasive grains. The hardness of the wheel varies with the strength of the bond.

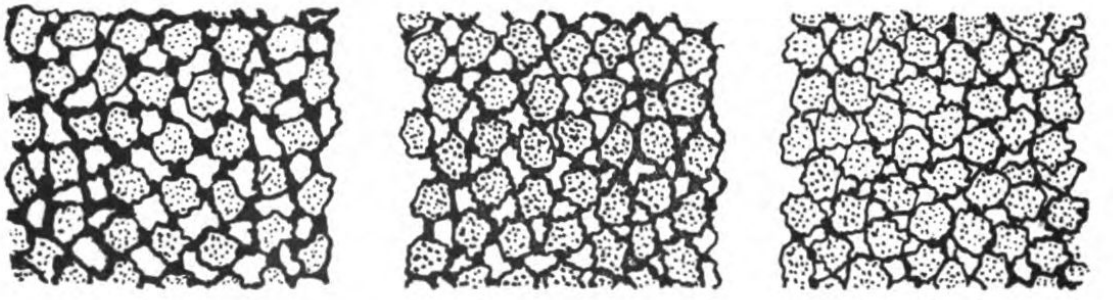


Fig. 186. Cross Section of three wheels identical in grain size and bond strength, but differing in grain spacing or structure providing correspondingly different grinding action

Vitrified Wheels. — Wheels most commonly used today are bonded by the vitrified process. The selected abrasive is mixed with a clay poured into molds and exposed to heat until the bonding material is vitrified. These wheels are of even texture and are unaffected by heat, cold, water, oils or acids. The porous texture of the wheel is advantageous because of the fact that in

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grinding, the abrasive grains are broken off and thrown away from the wheel, and as a result the wheel does not clog easily with the material being worked upon. The disadvantage of vitrified wheels is lack of elasticity and their not being able to be used on heavy side cuts.

The length of time required to make a vitrified wheel is also a disadvantage, as it requires about a month to make a finished wheel with a general limit in size of 36″ in diameter. With sizes larger than 36″ there is great danger of cracking in the mold.

Silicate Wheels. — Silicate wheels derive their name from silicate of soda which constitutes its bond. Silicate wheels cut smoothly with very little heat. They are adaptable for grinding work requiring a delicate edge, such as for tools and knives. Their grinding is dependable and the manufacture of these wheels can be controlled easily. Only a short time is required for their manufacture and silicate wheels can be produced up to 60″ in diameter.

Elastic Wheels. — Shellac is the most important bond used for elastic wheels. Shellac bonded wheels are strong and can be made very thin. The use of this bond makes possible wheels which produce a very smooth finish and which take deep cuts without burning the work. Shellac bonded wheels are also used in cutting off operations, for finishing chilled iron, cast iron and steel rolls, and for grinding in narrow spaces. This type of wheel is not intended for heavy duty.

Rubber Wheels. — Rubber forms a bond of great strength, and this type of wheel is used to cut grooves and where a good finish on the work is required. Rubber bonded wheels are capable of running at high speeds and rapid stock removal is possible at both high and low speeds.

In manufacturing, the rubber bond and the abrasives are mixed and rolled out in a sheet to the required thickness. The wheels are " died out " of this sheet and are heated in molds to vulcanize the rubber. This process makes possible very thin wheels.

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Resin Wheels. — Resin is mixed with an abrasive grain and a plasticisor to make the mixture elastic, cold molded and baked in an electric oven from 12 hours to 4 days, depending on the size of the particular wheel. A mixture of this type first softens, then increases in hardness with additional heat. Upon cooling, the extreme hardness of the bond is retained. This bond is used for the larger of the high speed wheels that are used in foundries. These wheels have a rate of stock removal in direct proportion to the operating speed and are designed to operate between 9,000 and 16,000 surface feet per minute.

Method of Numbering Abrasives. — Abrasives are classified by passing the particles through screens of various grades of mesh. The fineness of the particles is designated as grain and is indicated by the smallest size of screen mesh through which the particles will pass. For instance, the grain numbered 36 is one that will pass through a screen which has 36 meshes to the linear inch. In a standard table of abrasive numbers, very coarse abrasives are given a low number and designated as very coarse. As the numbers increase the grain grows finer and is designated as coarse, medium, fine, and very fine. Combinations of various size grits are also used in making grinding wheels, depending upon the particular requirements of the grinding operation.

Grade. — Grade refers to the hardness or softness of a wheel and is determined mostly by the strength of the bond used. Wheels whose abrasives tear out or break off easily are termed as soft grade wheels, and wheels whose abrasives do not easily break away are known as hard grade wheels. There are many intermediate grades among the various types of wheels, from very soft to very hard, and different methods are used by different manufacturers for expressing the grades.

Wheel Speed. — A wheel speed that is too slow wastes the abrasive of the wheel without getting the maximum performance from it, while an excessive speed may retard the cutting or possibly break the wheel. All wheels should be run at the speeds rec-

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ommended by the manufacturer. If a different speed is to be used, a change of grade with the same type of wheel should be used.

Recommended Wheel Speeds

	Surface Feet per Minute
Cylindrical Grinding	5,500 to 6,500
Internal Grinding	2,000 to 6,000
Snagging, Offhand Grinding (Vitrified Wheels)	5,000 to 6,000
Snagging, Rubber Bonded Wheels	7,500 to 9,500
Surface Grinding	4,000 to 6,000
Machine-knife Grinding	3,500 to 4,000
Hemming Cylinders	2,100 to 2,400
Wet Tool Grinding	5,000 to 6,000
Cutlery Grinding	4,000 to 5,000
Grinding with Rubber or Shellac Cutting-off Wheels	9,000 to 16,000

For cylindrical grinding, wheels should usually be run from 5,500 to 6,500 S.F.P.M., for surface grinding about 4,000-6,000, and for cutter grinding from 4,000 to 5,000 S.F.P.M. (surface feet per minute).

To find the surface speed of a grinding wheel in feet per minute when its revolutions per minute and diameter are known.

Rule. — Multiply 3.1416 by the diameter in inches, and by the revolutions per minute; then divide the result by 12.

To find the surface speed of a wheel in feet per minute when its revolutions per minute and circumference in feet are known.

Rule. — Multiply the circumference of the wheel in feet by the revolutions per minute.

If a wheel heats or glazes, run it slower. By increasing the speed, a soft wheel can be made to hold its size longer.

Caution. — A crack may not always be visible, so it is a good plan to test a wheel for soundness before starting it. This may be done by tapping the side lightly. If the wheel is sound it will ring clearly.

Work Speed. — The speed of the work has an effect upon a grinding wheel and this should be considered in making the selec-

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tion of a wheel. Fast work speed wears the wheel down faster than slower work speed. This should be understood as the wheel wear is dependent on the ratio of the wheel speed to the work speed. If the ratio is high, less work is required of the wheel in a given time, the wheel wearing at a slow rate. When the ratio is low, due to the increase of the work speed, more work is required from the wheel, in a given period, the wheel wearing faster.

In general, we may conclude that the work speed should be proportional to the grade and speed of the wheel and to the diameter of the work. Work speed may vary from 15 to 60 feet per minute depending on the character of the work. At the cutting point the wheel and work should turn in opposite directions.

Selection of Wheels. — The proper selection of a grinding wheel is important as grinding today plays an important part in manufacturing many products. Knowledge of the ability of the many different types of grinding wheels is helpful and the following aspects should be considered in their selection. The material to be ground and the amount of stock to be removed, its finish, the arc of contact of the wheel to the work and the machine on which it is to be used are important factors in the selection of a grinding wheel. The work and wheel speeds should also be considered.

The following is a helpful table for selecting wheels for different types of grinding and the wheels mentioned have been found satisfactory for the purpose specified. There may be others that are equally as good but space limits the suggestions that may be given. In some instances it may be advisable to vary from the list somewhat in the selection of a wheel for a certain job because of conditions applicable to that job alone, but the wheels suggested should prove satisfactory for the normal uses indicated.

Wheels for External Cylindrical Grinding

Suitable for	Material	Grain	Grade
Good all-round wheels. Best adapted to soft steel.	Aluminox	2946	L
	Alundum	3836	L
	Aloxite	401	N

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Wheels for External Cylindrical Grinding (*Cont.*)

Suitable for	Material	Grain	Grade
Hardened steel.	Aluminox or Alundum	46	K
Soft steel of small diam.		36	M*
Reamers, drills and general tool work.		80	K
Hard steel, dry grinding.		100	I
Cast iron and bronze.	Crystolon	45	L

Wheels for Facing Shoulders

Ordinary work.	Aluminox	60	H or I
	Alundum	60	H or I
Fine finish.	Aluminox or Alundum	80	I*

Wheels for Surface Grinding

Hardened steel.	Alundum or Aluminox	46	H
		46	G†
		60	F†
Hardened high speed steel or very thin pieces of hardened carbon steel.	Aloxite	367	U
	Alundum or Aluminox	46	G
Cast iron.	Carborundum or Crystolon	36	M
		36	J

Wheels for Disk Grinding

Thick pieces, wet grinding.	Aluminox or Alundum	30	K
Thin pieces, wet grinding.		30	J
High speed steel, dry grinding.		60 or 80	H or I
Washers and similar pieces		60	I

Wheels for Internal Cylindrical Grinding

Good all-round wheel.	Aluminox or Alundum	46	2* I*
Roughing hardened steel.		46	J or K
Finishing hardened steel.		120	J or K
Ordinary finish without roughing.		80 & 90	J or K
Roughing brass.	Crystolon	36	H or I
Finishing brass.		80	H
Automobile cylinders.		46	K

* Elastic Wheel † Silicate Wheel

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Wheels for Internal Cylindrical Grinding (*Cont.*)

Suitable for	Material	Grain	Grade
Automobile cylinders.	Carborundum	36	M to P
Automobile cylinders, roughing or fair finish.	Carbolite	36	H or I
Automobile cylinders, fine finish.	Carbolite	60	H

Wheels for Sharpening Cutters

(*Carbon steel, dry grinding*)

Milling Cutters. Formed and Gear Cutters.	Aluminox or Alundum	46 or 60	I

(*High speed steel, dry grinding*)

Milling Cutters. Formed and Gear Cutters.	Aluminox or Alundum	46 or 60	I

(*High speed steel, wet grinding*)

Milling and Gear Cutters.	Aluminox or Alundum	46	I

(*Carbon steel, wet grinding*)

Formed Cutters.	Alundum	46	J

Wheels for Tungsten Carbide Grinding

Tool Grinding			
Roughing	Green Crystolon	60	I
Finishing	Green Grit Carborundum	80 or 100	S
Roughing	Diamond Grit	100	
Finishing	Diamond Grit	150	

Mounting Wheels. — A wheel should fit easily upon the wheel sleeve, yet not loosely, for if loose it cannot be accurately centered and is consequently out of balance. Paper should not be wrapped around the spindle to make a wheel fit when the hole is too large. On the other hand, a wheel that fits a trifle tightly should never be forced on a spindle, as it may crack. If the hole is only a slight amount under size it can be easily scraped out with an old file; or, if lead bushed, a jackknife can be used

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to cut out enough metal to make the wheel fit easily on the spindle.

The flanges between which the wheel is secured should be at least one third of the diameter of the wheel; it is better to have them nearer one half that diameter. They should be relieved on their inner sides so that they bear against the side of the wheel only at the outer edge. The inner flange should be keyed or otherwise fastened securely to the spindle, and the outer flange should be keyed to the wheel sleeve to prevent it from turning and loosening the clamping nut. Flanges that are straight on their inner sides should never be used, for the tightening of the clamping nut will cause them to become slightly convex, bringing

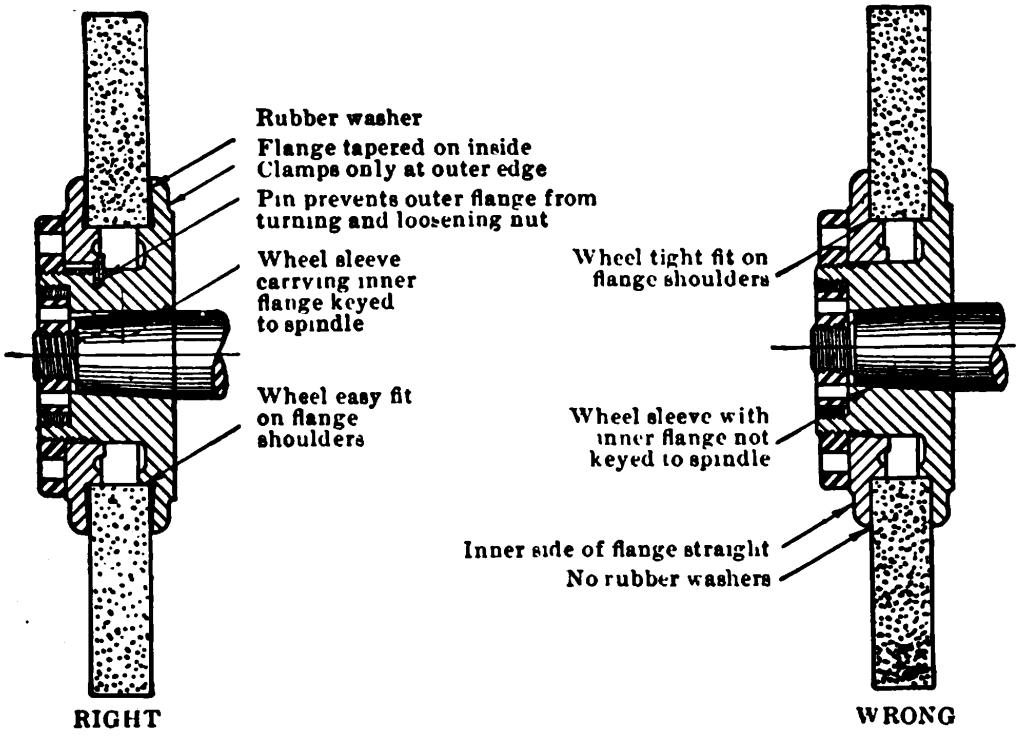


Fig. 187. Right and Wrong Way to Mount a Grinding Wheel

the pressure near the center instead of distributing it over the entire surface of that portion of the wheel enclosed between the flanges. Where the pressure is so concentrated there is danger of the wheel breaking.

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Frequent inspection of the flanges and clamping nut is important. If flanges become out of true or out of balance, they should not be used. Careful inspection is also necessary when a wheel has been broken to guard against putting back flanges that have been damaged.

Washers of leather, pulp, or rubber should be placed between the bearing surfaces of the flanges and the wheel. Some makers attach a ring of heavy blotting paper to each side of their wheels for this purpose, but it is a good plan to use leather or rubber washers in addition.

The clamping nut should be tightened just enough to hold the wheel firmly in place, otherwise clamping strain may cause the wheel to crack.

Balance of Wheel. — The balance of a wheel should be looked out for when selecting one, as it is very essential that it run perfectly true and without vibration. It will not run true if it is out of balance either from the lead core or from want of truing on the face. A wheel may also be out of balance from uneven density. In this case it cannot be corrected and a new wheel should be substituted.

Truing Wheels. — Great importance is attached by all makers to keeping grinding wheels true, for finish and production of work, for economy in wheel wear, and for safety to the operator. The diamond is always to be preferred for this purpose rather than any other device as it will give the most satisfactory results and last the longest.

The grade of a wheel and character of the work govern the frequency with which its surface should be trued. Soft grade wheels are apt to become untrue more quickly than those of the harder grades; but, on the other hand, there is a tendency to glaze on the part of hard grade wheels and this can be corrected only by dressing off the surface.

A new wheel that runs out considerably should be trued up at a slow speed. Its speed can then be safely increased to that at which it is to run. Then the face should be trued again as it

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does not necessarily follow that it will run true at a high velocity even if it does at a slow one.

To obtain the best results, when truing grinding wheels of large diameter or wheels for cylindrical or surface grinding, the diamond must be held in a fixed tool post or bracket, never held in the hand. There should be a constant flow of water or lubricant to keep the diamond cool and to avoid filling the air with dust. Wheels of small diameter or those used for small tool or reamer grinding, may be trued by holding the diamond in the hand.

Safety. — There is always more or less liability of grinding wheels bursting because of flaws, too high speed, being thrust into the work too abruptly or faulty mounting on the spindle. For this reason, standard grinding machines are fitted with a guard for covering the wheel to prevent injury to workmen and damage to the machine or surrounding objects in case of accident. When a wheel bursts beneath one of these guards there is comparatively little chance for it to do any damage. The pieces usually fall harmlessly to the machine or floor. Under no condition should a grinding wheel be operated without a guard. In case of accident where this has been done there is absolutely no excuse.

Use of Coolant. — Coolant is used in grinding principally to keep the work cool and prevent distortion which results if the temperature of a piece is allowed to change while it is being ground. It also serves to wash the particles of metal and loose abrasive from the surface of the wheel, keeping it clean and free-cutting.

A very slight change in temperature will sometimes cause serious inaccuracy in a finished piece of work; especially is this so in cylindrical work when a long slender piece is being ground. If water is not used here the heat generated is often sufficient to cause the piece to expand and bow toward the wheel, so that more stock will be removed than is intended, and the finished work will not be exactly round. Furthermore, its diameter will be

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smaller in the middle than at the ends. If cylindrical pieces of comparatively large diameter are ground dry they are apt to be under size when allowed to stand for a little while.

Water should be used whenever possible on cylindrical work. In surface grinding it should be used whenever there is much hardened work to be ground, although it can often be dispensed with in grinding cast iron. Internal grinding is usually done without water, owing to the liability of error in gaging holes from which all of the water cannot be easily removed.

To prevent rusting of the machine and work, just enough sal-soda (Sodium Carbonate) should be used in the water to show a slight deposit on the machine and finished work when dry.

For wet grinding a solution composed of one half pound of sal-soda to every gallon of water is recommended.

Other details regarding wheels and their selection will come to an operator as the result of observation and experience. Manu-

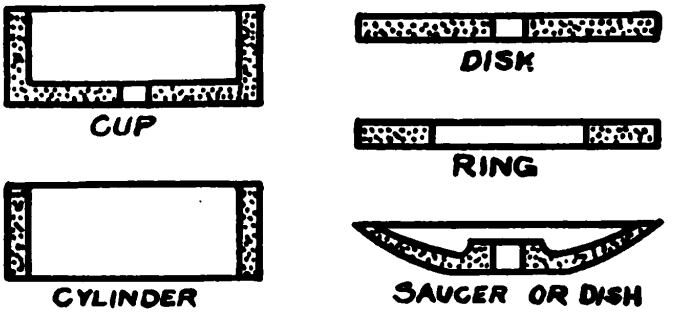


Fig. 188. Wheel Shapes

facturers of grinding machines and of grinding wheels, however, are in a position to give excellent advice as to the correct wheel to use where the material and conditions required are known, and until an operator becomes proficient in selecting them, we believe it is a good plan to rely upon the judgment of the manufacturer and study carefully the characteristics of the wheels advocated.

Polishing Abrasives

For polishing metal the following abrasives are in use: emery, corundum, alundum, carborundum, crocus, and rotten-stone.

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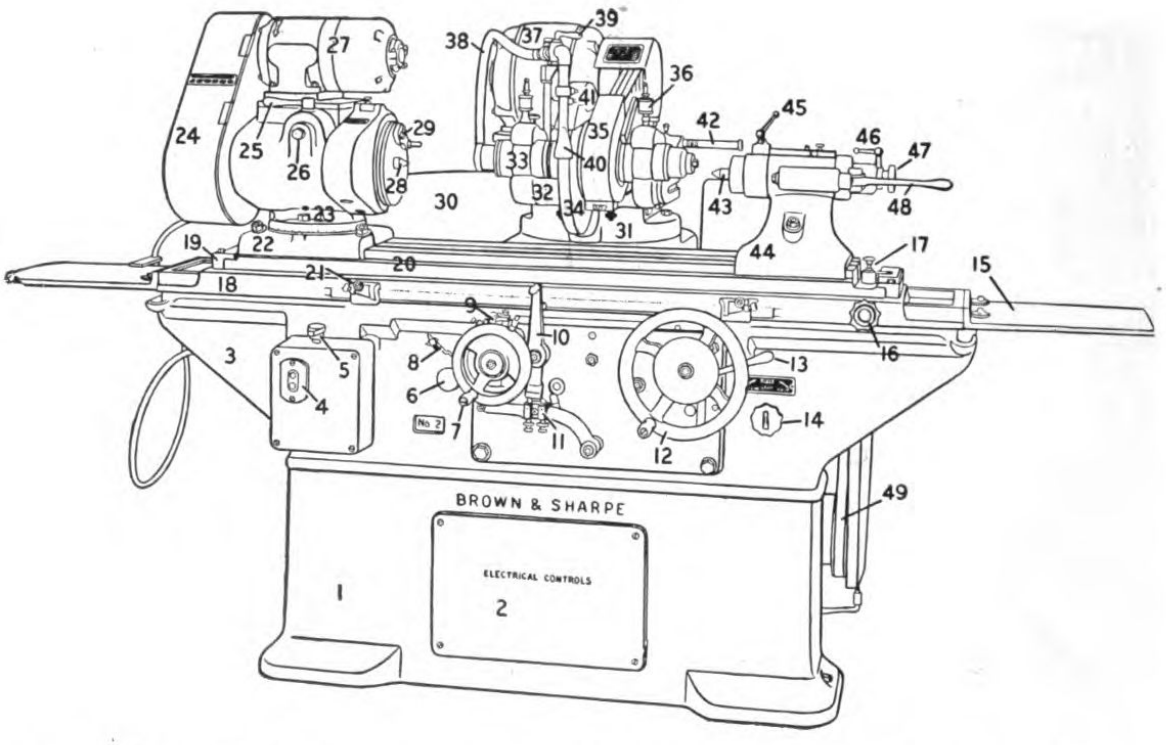


Fig. 189. Parts of a Universal Cylindrical Grinding Machine

1. Base
2. Electrical Controls Compartment
3. Bed
4. Main Push Button Switch
5. Headstock Control Knob
6. 4 to 1 Ratio Cross Feed Engagement Knob
7. Cross Feed Hand Wheel
8. Cross Feed Pawl
9. Cross Feed Stop Lever and Adjusting Lever
10. Table Reverse Lever
11. Cross Feed Lever and Adjusting Nuts
12. Table Hand Wheel
13. Table Feed Engagement Lever
14. Table Motor Selector Switch Knob
15. Table Guard
16. Swivel Table Adjusting Knob
17. Swivel Table Locking Pin
18. Sliding Table
19. Swivel Table Clamp
20. Swivel Table
21. Table Reverse Dog
22. Headstock Base
23. Headstock Body and Graduated Scale
24. Headstock Drive Belt Guard
25. Belt Tension Release Lever
26. Belt Tension Adjusting Nut
27. Headstock Driving Motor with Integral Brake
28. Headstock Center
29. Work Driving Pin
30. Pan Water Guard
31. Wheel Stand Platen
32. Wheel Stand
33. Wheel Spindle
34. Grinding Wheel
35. Wheel Spindle V Belt Guard
36. Sight Feed Oiler (for spindle bearing)
37. Wheel Spindle Motor
38. Coolant Hose
39. Coolant Control Valve
40. Coolant Nozzle
41. Wheel Guard
42. Internal Grinding Fixture
43. Footstock Center
44. Footstock
45. Diamond Tool Holder Clamp
46. Footstock Spindle Clamp
47. Footstock Spindle Adjusting Knob
48. Footstock Operating Lever
49. Lower Table Feed Driving Cone

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that have a rotary table like a vertical boring mill on which the work is held by a magnetic chuck (see Fig. 194) and the grinding is done on the end of a cup or cylinder wheel that turns in a plane parallel to the table. Cutter grinding machines are used for sharpening all kinds of drills, reamers and cutters.

Universal Grinding Machine. — The original universal grinding machine was developed to meet the need of a machine to grind needle bars, foot bars, and shafts for sewing machines. The first machine was an adaptation of a lathe and was developed by mounting an emery wheel on the carriage of a lathe. However, at the time, the need of a machine designed particularly for grinding was apparent, so in 1876 the first universal grinding machine was exhibited at the Philadelphia Centennial Exposition by the Brown & Sharpe Mfg. Co.

The universal grinding machine is now recognized as an indispensable machine tool in a well equipped shop. It has superseded the lathe to a great extent for finishing to exact measurements. It is provided with a headstock and footstock that are adjustable along a T slot in the swivel table. The headstock swivels through an arc of 90° either side of zero. Both the headstock and footstock are provided with centers, and, different from the lathe, the headstock is provided with an extra pulley for a " dead " center. The swivel table turns on a central stud and can be clamped at both ends. A graduated scale at the right-hand end indicates the amount of swing for taper work. The swivel table is carried by the main table of the machine which has longitudinal movement on ways in the bed. The bed contains the feed and reverse mechanisms, controlled by handles on the front of the machine.

The grinding wheel stand, shown in Fig. 189, remains stationary while grinding and the work is traversed. On some machines the wheel is traversed instead of the table. The grinding wheel stand is mounted on a slide and, by means of a handwheel on the front of the machine, the slide can be brought forward to the work or moved backward away from it. The slide is also pivoted

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on its base and can be clamped at various angles with the table guide ways. This construction permits abrupt taper work to be handled without swiveling the table. Universal grinding machines usually have more adjustments than plain grinding machines; they are adapted to do both internal and external grinding, straight or tapered, and even disk and general tool grinding.

Truing the Centers. — On universal machines it is merely necessary to remove both centers, clean out both holes carefully and place the center in the hole of the headstock spindle. Belt the headstock so that the " live " center will be turned, and after pulling out the locking pin, swivel the headstock to 30° and clamp. Traverse the table so that the wheel will true up the center with light cuts, until by trial and correction the point of the center fits the 60° center gage.

Setting the Table. — To set the table to grind straight work, make sure that the zero lines on the headstock graduations and the table swivel graduations coincide. Regardless of how carefully these adjustments may be made it will be necessary to put a piece of work between the centers, and after taking a light cut along the whole length of the piece, carefully measure the work at both ends with a micrometer caliper. If there is a difference in diameter make a slight adjustment of the table by turning the adjusting screw at the end. Continue in this way until the work is of the same diameter at both ends.

For slight tapers the table may be set by means of the swivel adjustment and the table graduations, but inasmuch as these graduations can only be approximate as to accuracy, a standard taper ring gage is necessary to test the taper for accuracy.

Where the work is held in a chuck on the headstock spindle, abrupt tapers can be ground by swiveling the headstock. When the work is between the centers, an abrupt taper can be obtained by setting the wheel slide at an angle. In the case of two abrupt tapers both headstock and wheel slide should be swiveled.

Feed or Traverse of Table. — The width of the wheel face and the quality of the finish desired should determine the traverse

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speed of the table. For roughing use a coarse feed and for large work on a large machine use a traverse of one half to three fourths the width of the wheel face to each revolution of the work. On less sturdy machines this may be modified to one third of the width of the face of the wheel. A highly accurate finish may be obtained with a traverse of one fourth to one third.

Depth of Feed. — For roughing, the depth of cut may be from .001″ to .004″ at each reversal: finishing from .00025″ to .0005″ at each reversal. From practice, it will be possible to determine whether a cut is light or heavy from the volume of the stream of sparks that issues from the cut.

Allowance for Cylindrical Grinding. — Work that is not to be hardened may be rough turned .006″ to .010″ large. Work that may be particularly large or long and slender, easily sprung or that is liable to spring after hardening should have an allowance of .020″ to .030″. When parts are being rough ground it is well to grind them to within .002″ or .003″ before finishing. Using this method the wheel has only to be trued occasionally.

Allowances for Fits. — The allowances given in the table on

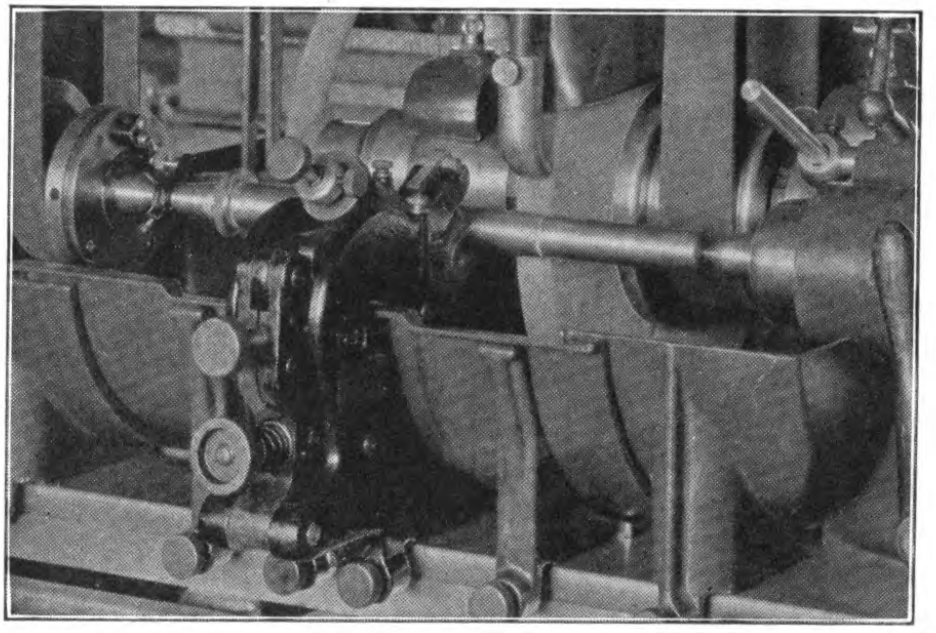


Fig. 190. Operation on a Universal Grinding Machine showing Water Guards and a Back Rest in Use

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Page 283 are recommended for use in the manufacture of machine parts, to produce satisfactory commercial work. These allowances should be followed only under ordinary conditions. For special cases, it may be necessary to increase or decrease the allowances given in the table.

Care and Oiling of Grinding Machines. — All wearing surfaces should be carefully guarded and kept well supplied with oil. Oil holes that are closed with screws should receive particular care to keep them free from dirt and grit while oil is being dropped into them. The whole machine should be kept as clean as possible. Bearings should not be allowed to "gum up," and when bearings are opened and exposed for any purpose they should be carefully wiped and re-oiled before they are closed again. See that the cross slide is clean, well oiled, and properly adjusted to move easily. Keep the center points true and well oiled.

The Plain Grinding Machine. — The plain grinding machine is essentially a manufacturing machine tool. It is made

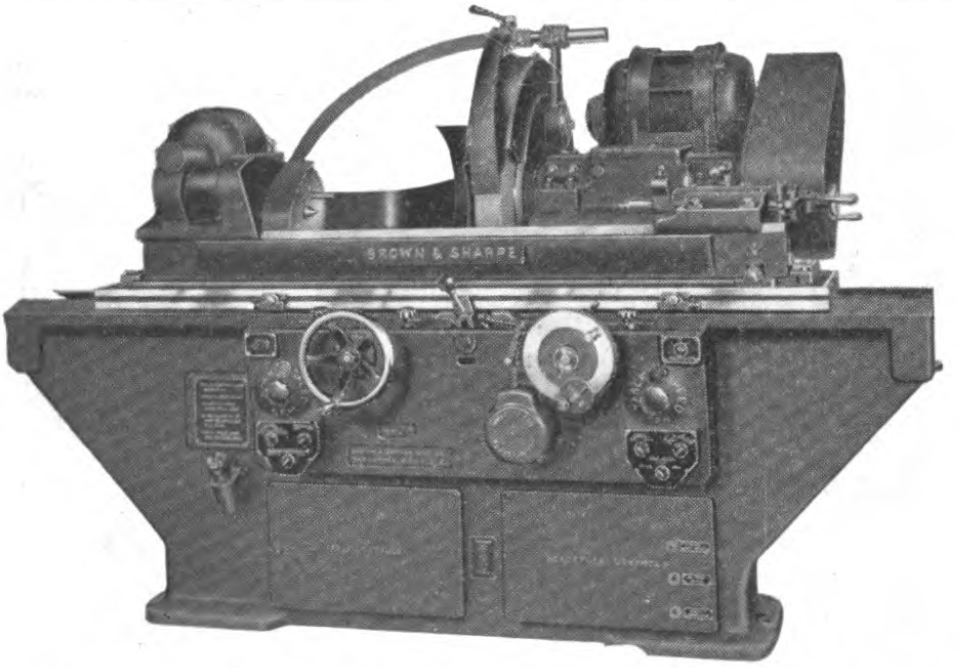


Fig. 191. An Electrically Controlled Manufacturing Type Plain Grinding Machine

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more rigid and sturdy to stand up under heavy cuts. Neither the headstock nor wheel slide is designed to swivel, and only straight and outside taper work can be accommodated. The shape of the swivel table is such that water guards of simple design are used. Otherwise the principal parts are similar to the universal grinding machine. On some types of plain grinding machines the wheel slide is traversed instead of the work. Fig. 191 shows a modern type of plain grinding machine with all operating functions of all major units of the machine governed electrically by controls grouped at the front within easy reach from the operating position.

Back Rests. — Back rests are accessory fixtures for supporting large or slender work so that vibration will be reduced and a greater depth of cut permitted.

The Plain Back Rest is used for short or small work and has a bronze shoe in contact with the rotating surface of the work.

The Universal Back Rest is universal in all its movements,

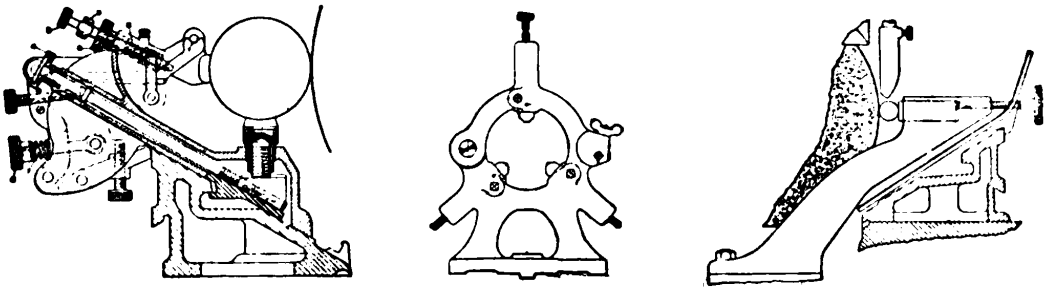


Fig. 192. At left, Combination Plain and Universal Back Rest, center, Center Rest, and at right, Follower Rest

and capable of the most delicate adjustment to maintain contact with and support the work.

The Center Rest is also an accessory and is used in the same way as a steady rest on an engine lathe.

Internal Grinding. — As its name implies, internal grinding is the operation of grinding straight or tapered holes, smooth and true, in work held by a universal or on a special internal grinding machine. When this kind of work is done on either a

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universal or universal and tool grinding machine the attachment shown in Fig. 193 is bolted to the wheel platen.

Wheels for Internal Grinding. — Due to lack of rigidity attainable for this operation and the consequent necessity for

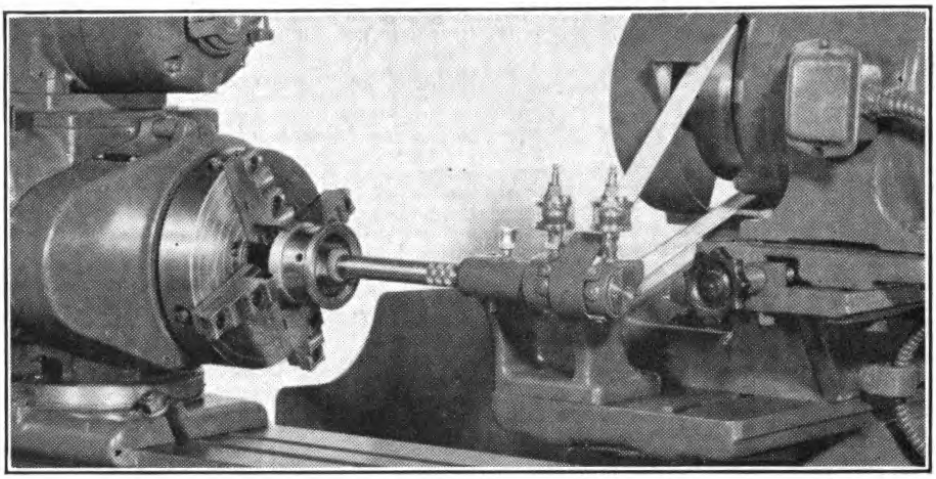


Fig. 193. Internal Grinding Attachment in Use

reducing to a minimum the pressure of the grinding wheel on the work, it is necessary to use softer wheels for internal grinding than for external work. Vitrified wheels from 1/4″ to 2 1/2″ diameter and 1/4″ to 3/8″ face are used. Wheels most commonly used are Nos. 120, 90, 80, 70 and 60 — grades *J*, *K*, 1/4, 1/2, and 1. Elastic wheels are recommended on brass.

Surface Grinding. — Surface grinding or the finishing of plain surfaces originally was done with a grinding wheel attached to a planer. As time went on a new type of machine with a vertical spindle appeared. The heavier types of surface grinding machines work right from the rough casting. They are amazingly fast and accurate.

The Vertical Spindle Surface Grinding Machine. — The table of the vertical spindle surface grinding machine revolves while it is being fed toward the wheel (see Fig. 194). The machine is generally known as the rotary type. The wheel spindle can be raised and lowered by power. The grinding wheel runs at one speed but the work table is provided with several speeds.

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The coolant flows from the center of the wheel and is distributed by centrifugal force between the wheel and the work.

The rotary speed of the table as well as the crosswise feed of

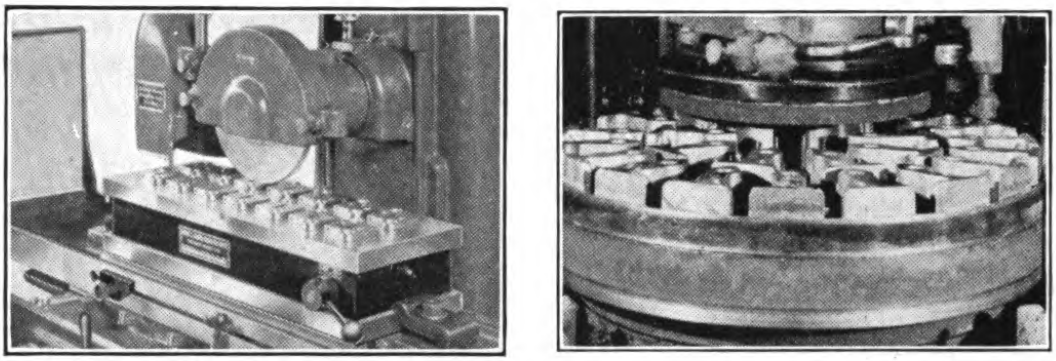


Fig. 194. At left, Magnetic Chuck on Table of Surface Grinding Machine and at right Verticle Spindle Grinding Machine with Rotating Table. Work is held by Magnetic Chuck

the table and also the raising and lowering of the grinding wheel are controlled by levers and handwheels.

The Surface Grinding Machine. — Figure 195, is a grinding machine that can be used to advantage on production operations as well as on toolroom work. It is accurate and easy to set up. The table travel is automatic and is controlled by adjustable dogs that trip a reversing lever. The transverse movement is also automatic and feeds from .01″ to .09″ at the end of each stroke.

Magnetic Chuck. — The magnetic chuck is frequently used to hold the work on surface grinding machines. See Figs. 194, and 196. These magnetic chucks are of two types — Electro-magnetic and Permanent Magnet. Permanent Magnet Type Magnetic Chucks have the advantages of electro-magnetic chucks but do not require electric current as they are constructed with permanent magnets. Electrical connections, wires, switches or auxiliary generators are unnecessary. The magnets are of a special alloy. They have a strong holding power and last indefinitely. A simple 180° movement of a crank holds or releases

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the work. The chucks do not heat under any conditions, so that work can be held on them as long as desired without damage to work or chuck, an advantage for many uses.

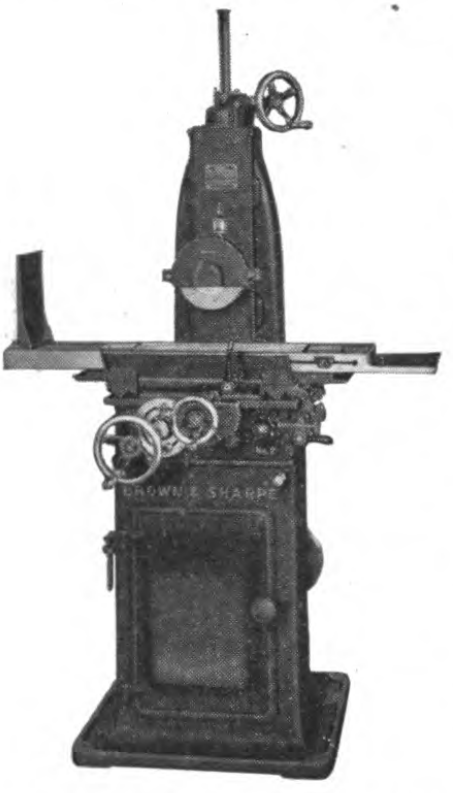


Fig. 195. A Common Type of Surface Grinding Machine

Wheels and Speeds. — Vertical type surface grinding machines are ordinarily operated at wheel speeds ranging from 4000 to 4500 F.P.M. The work speed may be 90 F.P.M. for the vertical spindle type, and about 30 F.P.M. for the planer type. Coarse, soft wheels usually give the most satisfaction.

Universal and Tool Grinding Machine. — This machine is used to grind tooth clearances on cutters, reamers, and tools. In addition, it is practicable for light cylindrical and surface grinding jobs. It is essentially a toolroom machine and a necessary accessory to the milling machine. Attachments are available for sharpening hobs and convex and concave

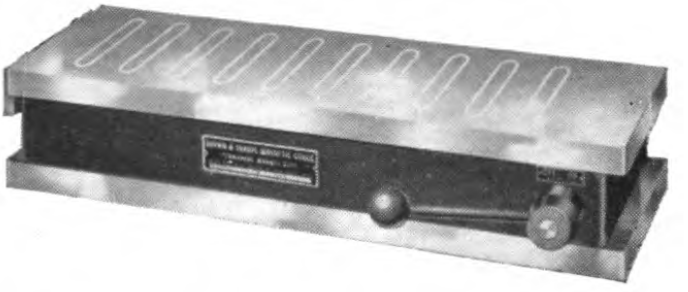


Fig. 196. Magnetic Chuck, Permanent Magnet Type

cutters of the milling cutter type; for internal, surface and wet grinding operations and for indexed work.

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The machine is very similar to a universal grinding machine except that the spindle carries two wheels and is mounted on a slide that is adjusted vertically by a handwheel at the top. The spindle slide upright has a transverse movement and also swivels, the swiveling movement being measured by graduations on the base. The table swivels and is automatic in its move-

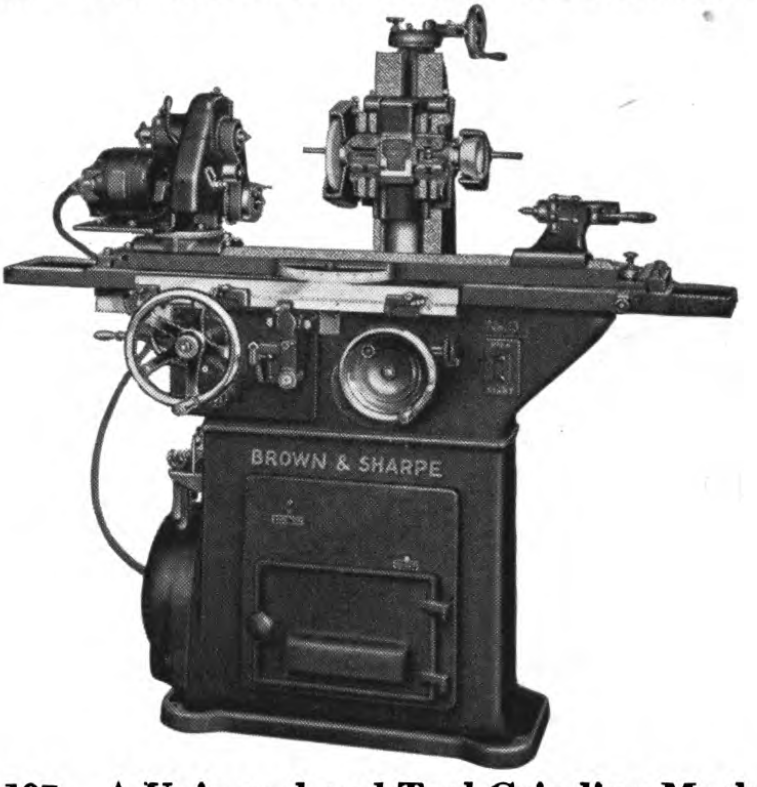


Fig. 197. A Universal and Tool Grinding Machine

ment although it can also be moved by hand by means of a handwheel on the bed. The machine is adaptable to practically any kind of a grinding job that may arise.

Grinding Tooth Clearance. — Disk Wheel. The clearance of the teeth back of the cutting edges is obtained, when the teeth face downward, by having the center of the cutter below the horizontal plane of the axis of the wheel as in A, Fig. 198. When the teeth face upward, as in B, the center of the cutter should be slightly above the center of the wheel. The dotted center lines illustrate this. The tooth rest should be on the horizontal center of the cutter.

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Cup Wheels. — When using a cup wheel the amount of offset of the wheel depends on the diameter of the cutter to be ground. The tooth rest is set either above or below the horizontal center of the cutter depending upon the direction the teeth face. See Fig. 198, C and D.

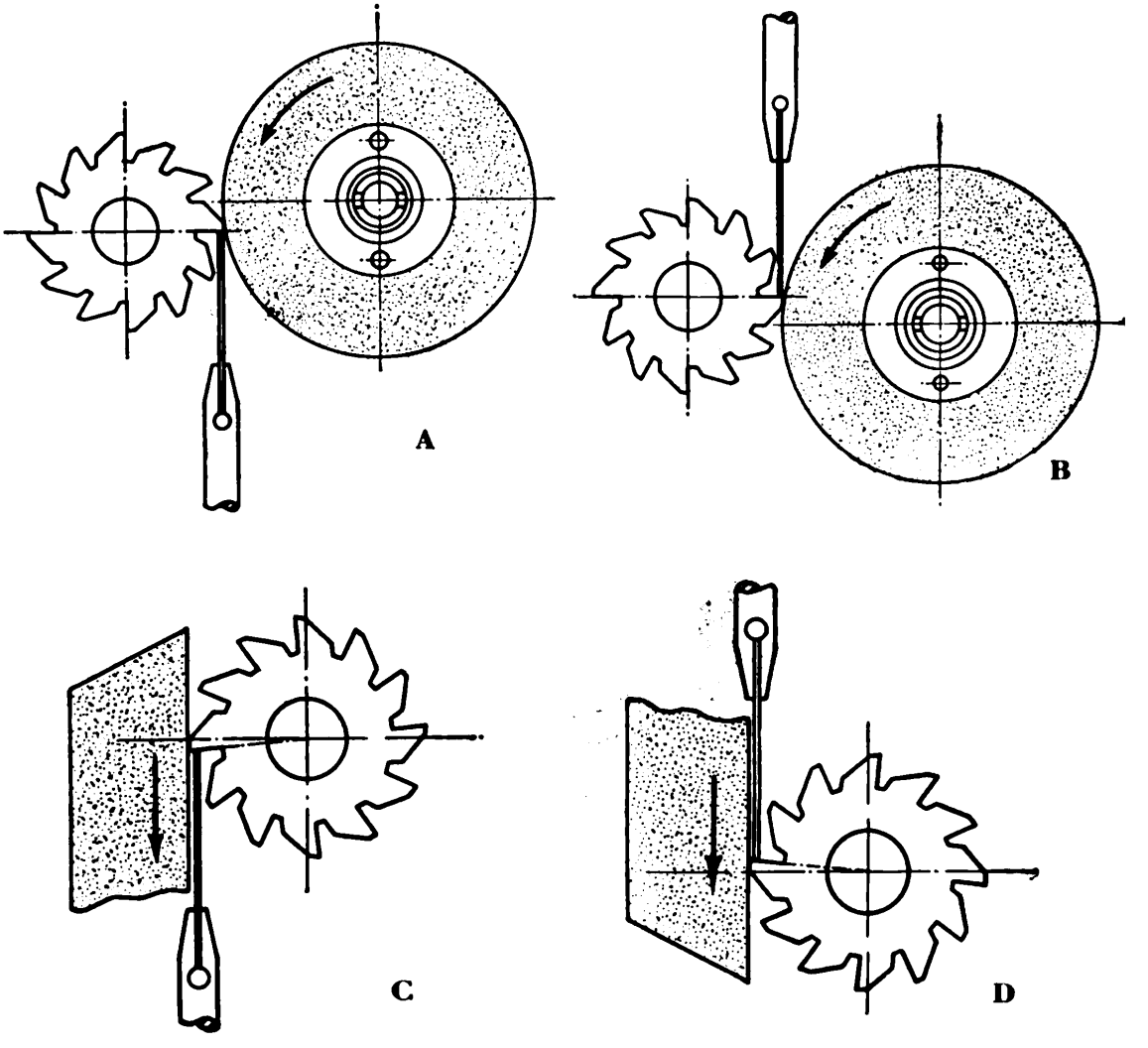


Fig. 198. Position of the Cutter with Relation to the Wheel when Grinding Clearances

The Best Clearance Angle. — The angle of clearance depends on the diameter of the cutters. It is greater for small cutters than for large ones. The clearance on the teeth of plain milling cutters should be from 4° to 5° for cutters over 3″ in

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diameter, and from 6° to 7° for those under 3″. The lands at the top of the teeth should be from .02″ to .04″ wide, before the clearance is cut or ground. The clearance of the end teeth of end mills should be about 2°, and it is well to have the teeth a trifle concave, making them .001″ or .002″ lower near the center than at the outside, so that the inner ends of the teeth will not drag on the work. If the clearance of a cutter is too great, vibration is likely to occur in operation.

Suggestions in Regard to Cutter Grinding. — Sharpen cutters often. It is important that they be kept sharp. Experience has shown that a dull cutter wears more rapidly than a sharp one, and that if a cutter is continued in use until its teeth are quite rounded or burnt, it will be necessary to grind off considerable stock from each tooth in order to restore its correct cutting edge. Therefore, a cutter that is kept in good condition by frequent sharpening will invariably outlast one that is neglected.

Disk Wheels and Cup Wheels. — Both disk wheels and cup wheels are used for sharpening cutters. The disc wheel, which is perhaps used more commonly, leaves a slight concavity on the land whereas the cup wheel produces a straight clearance or land. Generally, this slight difference is not important, although one advantage claimed for cup wheel sharpening is a better finish on the work which the cutters, sharpened with a cup wheel, produce.

The limitations of this book will not permit much detailed discussion of the construction and operation of grinding machines. Further information may be obtained from the books on grinding machines listed at the back of this book.

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CHAPTER IX

Gears and Gear Cutting

Kinds of Gears. — There are four kinds of gears that are ordinarily cut in a machine shop: spur gears (including racks and internal gears), helical or spiral gears, bevel gears and worm gears, Fig. 199.

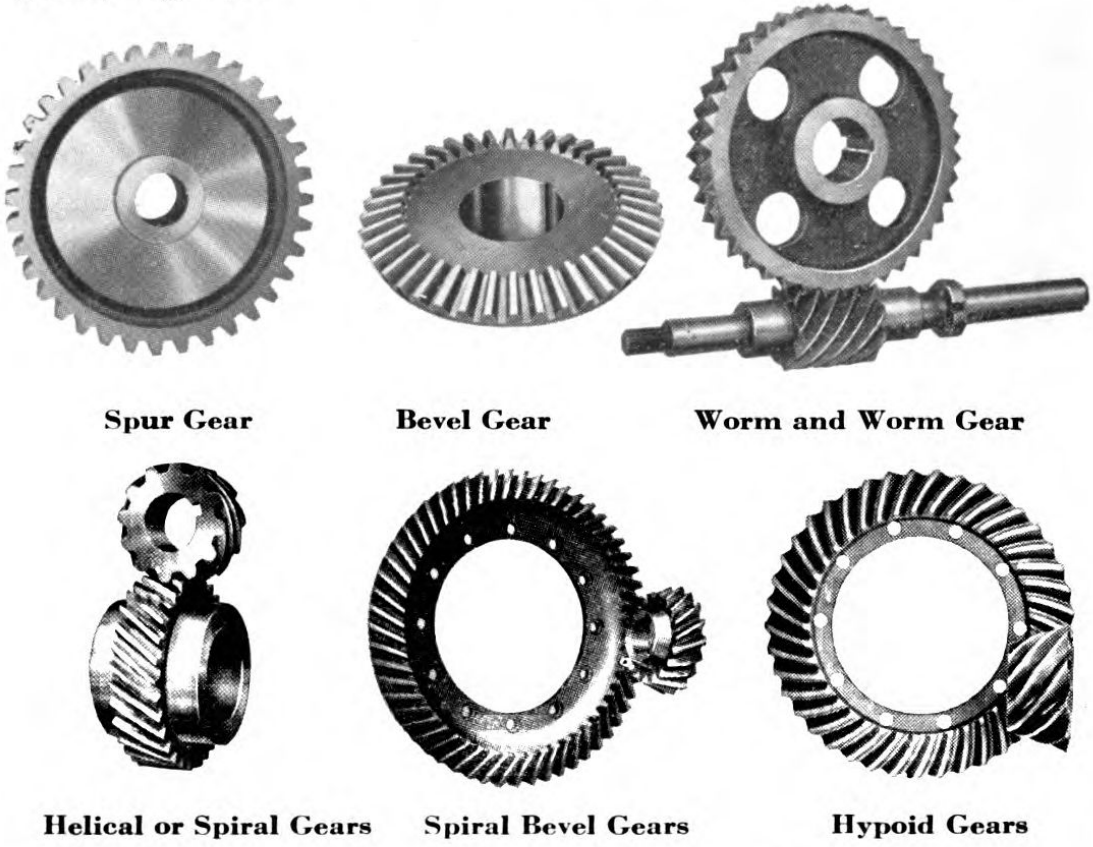


Fig. 199. Different Types of Gears

Spiral Bevel Gears and Hypoid Gears also shown are variations of bevel and spiral gears with characteristics of both and are described in later pages of this chapter. Special equipment is required to produce them.

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Gear Teeth. — In spur gearing there are two recognized forms of teeth: the cycloidal and the involute. At the present



Fig. 200. A 10 Tooth Pinion at left, with undercut and pressure angle of 14½°; and at right, without undercut and having a pressure angle of 28°

time the involute form is used almost exclusively, the cycloidal form being used only for certain special purposes such as for the driving of printing press rolls.

Advantages of the involute form are that it presents fewer difficulties when cutting; also that it is the only form of tooth which permits the center distance to be varied slightly and still have the gears transmit uniform motion.

The involute form is commonly made with its pressure angle varying from 14½° to 30°. Fig. 200 shows two involute forms with 14½° and 28° pressure angles. The involute form of gear is made to both standard and short depths. Teeth of short depths are made in several proportions and are called "Stub Teeth."

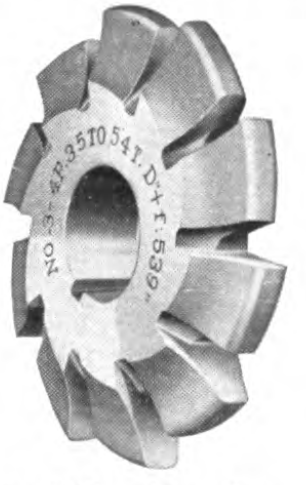


Fig. 201. Involute Spur Gear Cutter

Involute Gear Cutters. — The pitch and number of teeth in a gear have a direct effect on the shape of a tooth, so that for a highest degree of accuracy it is necessary to have a particular cutter for each pitch and number of teeth. However, it has proved to be practicable to use one cutter to cut gears having several different numbers of teeth without causing great error in the result. In the involute system eight cutters

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are usually available for each pitch and they will cut gears from a pinion of twelve teeth to a rack. Although the majority of cutters are intended to cut gears of diametral pitches, yet cutters are also available to cut common circular pitches.

Formed cutters for cutting gears are made of either carbon or high speed steel. Their design is such that they can be

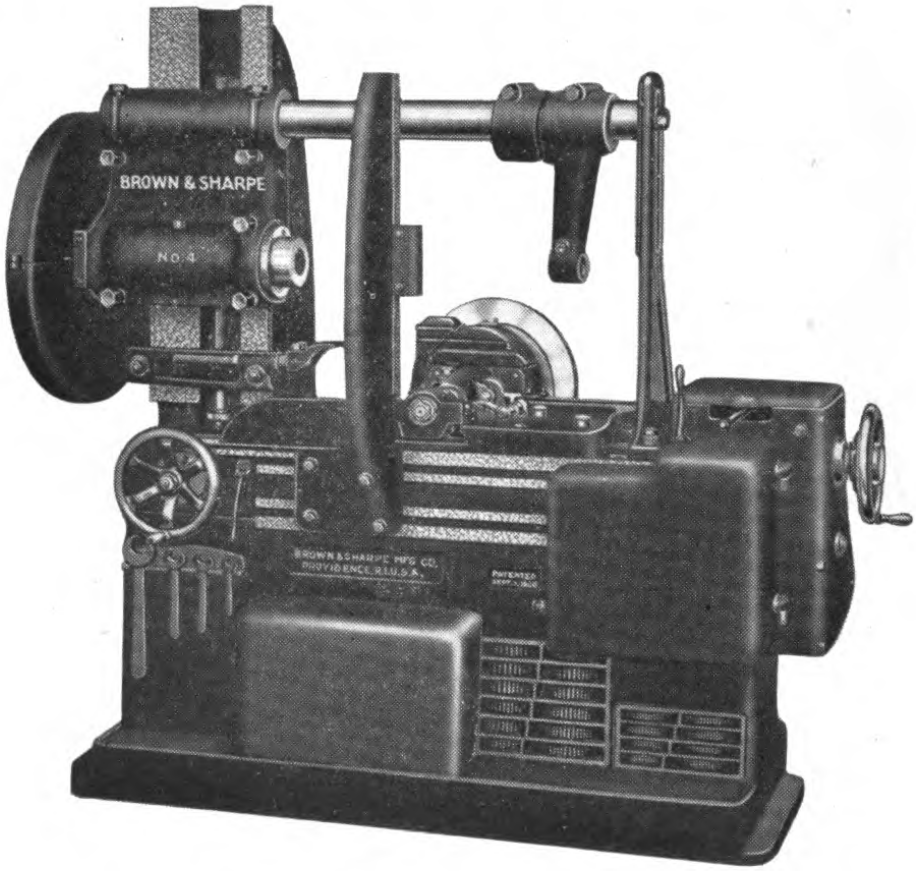


Fig. 202. An Automatic Spur Gear Cutting Machine

sharpened by grinding the faces of the teeth without altering their form.

Milling Process. — There are various methods of cutting gears. A milling machine can be used for cutting gears by using the proper attachments. This method is used, however, only where a few gears are required and where the flow of work does not justify an expenditure for a production gear cutting machine.

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The automatic spur gear cutting machine shown in Fig. 202 is, in reality, a form of milling machine designed to meet the requirements of gear cutting.

Gear Cutting Machine. — On this machine the gear blank is mounted on the spindle of the sliding head. After each tooth is cut it is indexed by an automatic indexing mechanism at the

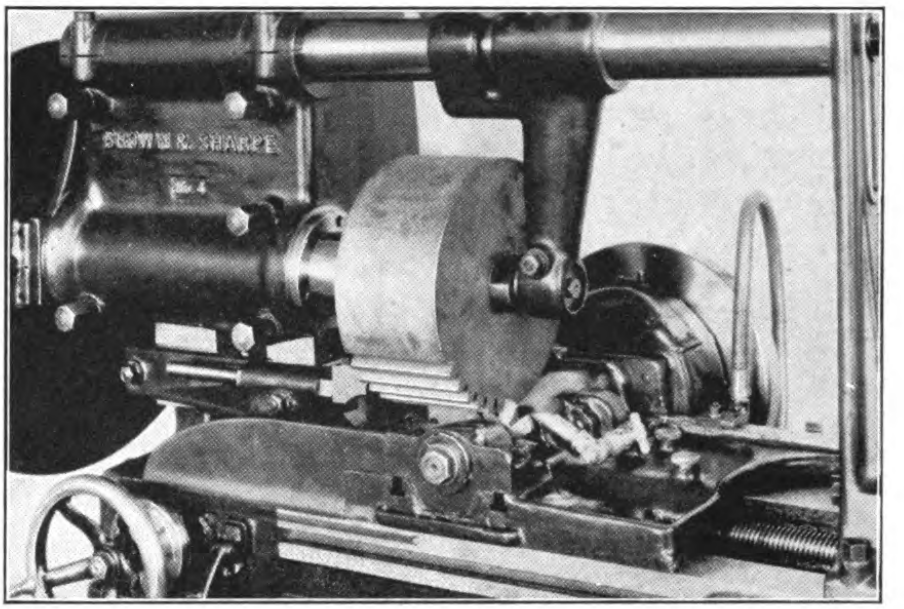


Fig. 203. Cutting a Spur Gear on an Automatic Spur Gear Cutting Machine

rear of the upright. The formed cutter is mounted on the cutter spindle in the cutter slide. The slide reciprocates automatically and cuts a tooth space at each movement. Figure 203 shows a machine of the above type and Fig. 204 shows one adapted for cutting bevel gears and clutches in addition to spur gears. This is accomplished by a bed under the cutter slide that can be elevated through the arc of a circle to 90°.

The Sizing and Cutting of Gears

Diameter, when applied to gears, is usually understood to mean the pitch diameter. However, outside diameter is quite

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frequently used and it is good practice to make certain which of the diameters is meant.

Diametral Pitch is the number of teeth to each inch of the pitch diameter.

Example. — If a gear has 40 teeth and the pitch diameter is 4″, there are 10 teeth to each inch of the pitch diameter and the diametral pitch is 10.

Diametral Pitch required, circular pitch given. Divide 3.1416 by the circular pitch.

Example. — If the circular pitch is 2″, divide 3.1416 by 2, and the quotient, 1.5708, is the diametral pitch.

Diametral Pitch required, number of teeth and outside diameter given. Add 2 to the number of teeth and divide by the outside diameter.

Example. — If number of teeth is 40, and diameter of blank is 10 1/2″; add 2 to number of teeth, making 42, and divide by 10 1/2; the quotient, 4, expressed in inches, is diametral pitch.

Circular Pitch is the distance from the center of one tooth to the center of the next, measured along the pitch line.

Example. — If the distance from the center of one tooth to the center of the next tooth, measured along the pitch circle, is 1/2″, the gear is 1/2″ circular pitch.

Circular Pitch required, diametral pitch given. Divide 3.1416 by the diametral pitch.

Example. — If the diametral pitch is 4″, divide 3.1416 by 4, and the quotient, .7854″, is the circular pitch.

Number of Teeth required, pitch diameter and diametral pitch given. Multiply the pitch diameter by the diametral pitch.

Example. — If the diameter of the pitch circle is 10″ and the diametral pitch is 4, multiply 10 by 4, and the product, 40, will be the number of teeth in the gear.

Number of Teeth required, outside diameter and diametral pitch given. Multiply the outside diameter by the diametral pitch and subtract 2.

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Example. — If the whole diameter is 10 1/2″ and the diametral pitch is 4, multiply 10 1/2 by 4, and the product, 42, less 2, or 40, is the number of teeth.

Pitch Diameter required, number of teeth and diametral pitch given. Divide the number of teeth by the diametral pitch.

Example. — If the number of teeth is 40 and the diametral pitch is 4, divide 40 by 4, and the quotient, 10, expressed in inches, is the pitch diameter.

Outside Diameter or size of gear blank required, number of teeth and diametral pitch given. Add 2 to the number of teeth and divide by the diametral pitch.

Example. — If the number of teeth is 40 and the diametral pitch is 4, add 2 to the 40, making 42, and divide by 4; the quotient, 10 1/2, is the whole diameter of the gear or blank.

Thickness of Tooth at Pitch Line required. Divide the circular pitch by 2, or 1.57 by the diametral pitch.

Example. — If the circular pitch is 1.047″, and the diametral pitch is 3, divide 1.047 by 2, or 1.57 by 3, and the quotient, .523″, is the thickness of tooth.

Whole Depth of Tooth required. Divide 2.157 by the diametral pitch.

Example. — If the diametral pitch of a gear is 6, the whole depth is 2.157 divided by 6, which equals .3595.

Whole Depth of Tooth is equal to the product of .6866 multiplied by the circular pitch.

Example. — If the circular pitch is 2″, the whole depth of tooth is .6866 × 2″, or 1.3732.

Distance between Centers of two gears required. Add the number of teeth together and divide one half the sum by the diametral pitch.

Example. — If two gears have 50 and 30 teeth, respectively, and are 5 pitch, add 50 and 30, making 80, divide by 2, and then divide the quotient, 40, by the diametral pitch, 5, and the result, 8″, is the center distance.

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Speed of Cutters. — Using carbon steel cutters, brass may be cut at a speed of 80 feet per minute and up; cast iron, 40 to 60 F.P.M.; machinery steel, 30 to 40 F.P.M., and annealed tool steel, 20 to 30 F.P.M.

High speed steel cutters may have a speed on brass of 150 F.P.M. and up; on cast iron and machinery steel, 80 to 100 F.P.M., and on annealed tool steel, 60 to 80 F.P.M. It should be kept in mind that the speed of the cutter may be anywhere within these limits, or even in extreme instances greater or less. For tables of R.P.M. for various cutting speeds and diameters, see pages 294 and 295.

The change gears necessary to give the speed desired are indicated on the speed table furnished with the machine.

Feed of Cutter Slide. — The rate of feed varies so widely under different conditions, while slight changes have such a marked effect on the cost and quality of the product, that no specific rates can be given as correct for an individual job. The best method is to start with a moderate feed, then increase it until the gear blank can stand no more or until the economical limit of the cutter is reached. The table on page 201 is submitted as a suggestion of what these feeds might be.

The most economical feed is not usually the fastest which the cutter will stand without burning or breaking. This is due to the fact that with a very high rate of feed, the cutter must be sharpened frequently, which consumes considerable time. There is also the risk of a ruined cutter. A slightly slower feed in such a case will not greatly decrease the rate of production, while it will, on the other hand, allow the cutter to hold its edge much longer. The result will be that the net production per cutter will be greater at the slower feed and the production per day will be as great. This reduces the cutter cost per gear produced, inasmuch as the cutters last much longer under the slightly slower feed. In addition, smoother cuts will result due to the fact that the "revolution marks" of the cutter will be more closely spaced and less pronounced.

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Most of the cutters used in manufacturing are of high speed steel and the following table will give useful data for the feed of these cutters:

Feed of High Speed Steel Cutters

Diam. Pitch		1½	1¾	2	2½	3	4	5	6	7	8	10	12	16
Feed, Inches per Minute	C.I.	2¾	3½	4	4	4½	5	6	6	7	7	8	9	11
	Steel	1½	2	2½	2½	3	3	3½	3½	4½	4½	5	6	8

A table furnished with each machine indicates the change gears to be used for the desired feed.

Cutting Bevel Gears. — Bevel gears are used to transmit power or movement between shafts that intersect at an angle. A bevel gear may be milled or generated. The milling process, however, does not produce a theoretically perfect outline for a bevel gear tooth. The curve of a tooth, when correctly formed, changes constantly from one end of the tooth to the other. Therefore, bevel gears, the teeth of which are produced with a cutter with a fixed curve, are not theoretically correct. The cutter usually has a curve that will make the correct form at the outer part of the face of the gear, but it will naturally leave the curves too large at the inside end.

Bevels of medium and small pitch are frequently cut by the milling process, particularly when the requirements are not too exacting. Coarse pitch gears and gears that run at high speeds are usually roughed out by the milling process and finished by generating.

On most bevel gears that are cut with a fixed curve cutter, it is necessary to cut through the blank twice, setting the cutter off center; first to one side and then to the other. Thus the tooth can be tapered.

When milling cutters are used to cut bevel gears, the length of face of the gear should not be longer than one third of the apex distance.

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Setting the Cutter Off Center. — In cutting cast iron gears coarser than 5 diametral pitch it is better to take one roughing cut entirely around the blank, with the cutter set " central," before attempting to find the correct setting of the cutter or rotation of the blank for the correct thickness of teeth. It is generally advantageous to take a central cut on nearly all bevel gears of steel. Inasmuch as the thickness of the cutter teeth should not be greater than the width of the space at the small

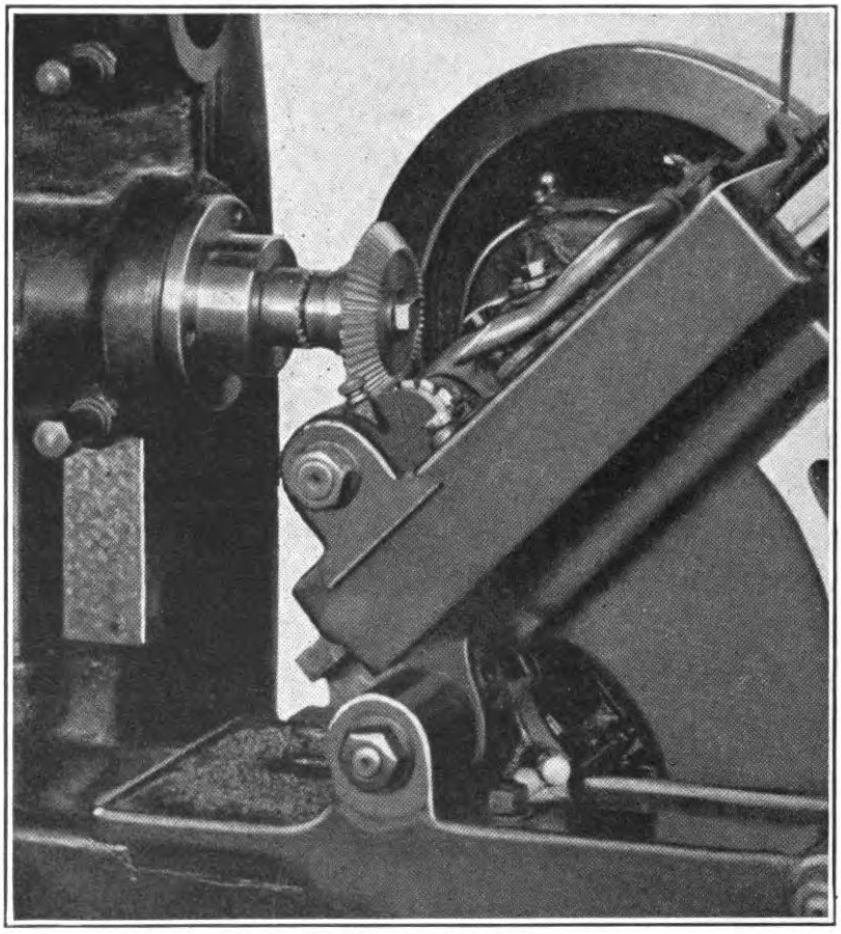


Fig. 204. Cutting a Bevel Gear on an Automatic Spur and Bevel Gear Cutting Machine

end of the teeth, it is necessary to set it off center and to rotate the blank in order to make the spaces the correct width at the large end of the teeth.

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The amount to set the cutter off center can be calculated by means of the following table and formula.

$$\text{Set over} = \frac{Tc}{2} - \frac{\text{Factor from table}}{P},$$

where P = diametral pitch of gear to be cut and Tc = thickness of cutter used, measured at pitch line. Given as a rule, this would read: Find factor in the table corresponding to the number of the cutter used and to the ratio of apex distance to width of face; divide this factor by the diametral pitch and subtract the quotient from half the thickness of the cutter at the pitch line.

TABLE FOR OBTAINING SET OVER FOR CUTTING BEVEL GEARS

No. of Cutter	Ratio of Apex Distance to Width of Face												
	3/1	3¼/1	3½/1	3¾/1	4/1	4¼/1	4½/1	4¾/1	5/1	5½/1	6/1	7/1	8/1
1	.254	.254	.255	.256	.257	.257	.257	.258	.258	.259	.260	.262	.264
2	.266	.268	.271	.272	.273	.274	.274	.275	.277	.279	.280	.283	.284
3	.266	.268	.271	.273	.275	.278	.280	.282	.283	.286	.287	.290	.292
4	.275	.280	.285	.287	.291	.293	.296	.298	.298	.302	.305	.308	.311
5	.280	.285	.290	.293	.295	.296	.298	.300	.302	.307	.309	.313	.315
6	.311	.318	.323	.328	.330	.334	.337	.340	.343	.348	.352	.356	.362
7	.289	.298	.308	.316	.324	.329	.334	.338	.343	.350	.360	.370	.376
8	.275	.286	.296	.309	.319	.331	.338	.344	.352	.361	.368	.380	.386

Bevel Gear Cutters. — Special cutters are made for this purpose. They have the involute form of tooth but with thinner teeth than the regular cutters. Bevel gear cutters are numbered from 1 to 8. They cut all numbers of teeth from 12 to a crown gear.

Data Required for Cutting Bevel Gears. — The following data is required to cut bevel gears: pitch and number of teeth; whole depth of tooth spaces at both large and small ends of the teeth; thickness of the teeth at both ends; height of the teeth

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above the pitch line, or addendum at both ends; length of face; angle between the shafts; and the cutting angle or the angle to set the cutter slide carriage.

While cutting bevel gears with rotary cutters, the cutting angle is equal to the working depth angle, that is, the line of the bottom of the tooth is parallel to the face of the mating gear and it does not pass through the cone apex or common joint of the axes.

Selection of a Bevel Cutter. — There are two rules for determining the cutter to use on bevel gears.

(1) Multiply the back cone radius by 2, and multiply this product by the diametral pitch of the gear. By referring to a table of involute cutters for bevel gears, the number of the cutter

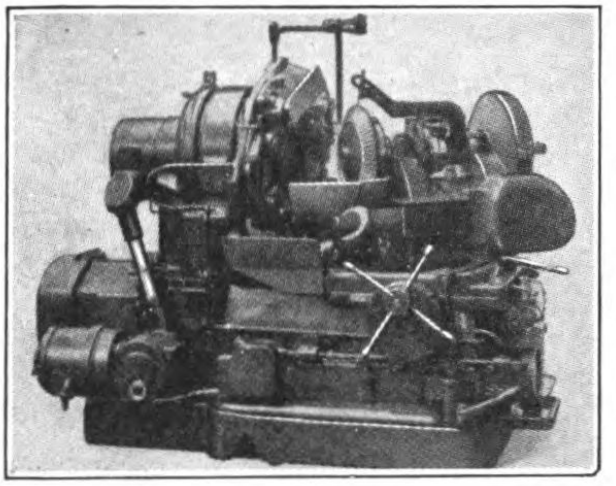


Fig. 205. Gear Generator for Straight Tooth Bevel Gears

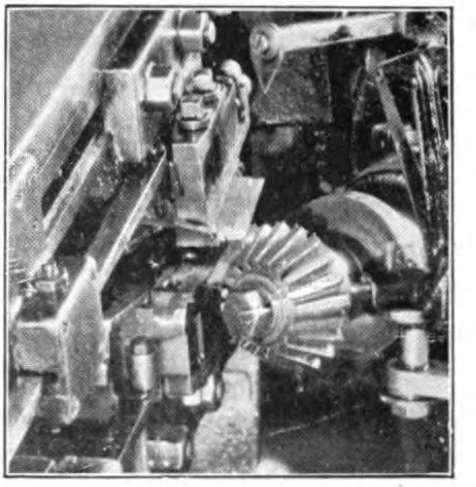


Fig. 206. Cutting a Bevel Gear on a Gear Generator

can be determined by taking this final result and finding which cutter in the table corresponds to it.

The other rule is as follows:

(2) Divide the number of teeth in the bevel gear by the cosine of the pitch angle. The result will be the number of teeth for which the cutter is selected.

Bevel Gear Generating Machine. — In the case of the two tool generative bevel gear planer the teeth of a gear are

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formed by two cutters working with a reciprocating motion on each side of the tooth. Each tool cuts alternately on its forward stroke and as soon as a tooth is finished the machine automatically indexes so that the next one is brought into position.

The bevel gear blank is mounted on a spindle that is firmly attached to a semi-circular arm. A segment of a master gear is attached to the arm. It engages with the sector of a crown gear. The crown gear which is connected with the cutter slides can be set to any angle and the tooth size is obtained by adjusting the slides carrying the tool holders. By means of a cam and slotted link a rolling and generating motion is produced between the cutters and the gear blank. The indexing is automatic by a worm, worm gear, and change gear mechanism.

Spiral Bevel Gears. — The difference between spiral bevel gears and straight bevels is that the former have teeth of a spiral or curved form, the curve of the teeth of one member being right-hand and those of the mating member, left-hand.

Spiral bevels may be substituted in place of straight bevels, the only necessary precaution being to provide suitable thrust bearings to take the increased thrust.

The teeth of spiral bevels come into contact gradually instead of touching across the entire face instantaneously. This increases the average number of teeth in contact and makes the gears stronger and more quiet.

Method of Cutting Spiral Bevel Gears. — Spiral bevel gears have their teeth curved on the arc of a circle to obtain gradual engagement and overlapping contact. A circular cutter of the face mill type, see Fig. 207, is used. The blades have straight sided cutting edges to correspond to the tooth shape of a crown gear. The teeth are generated by rolling the revolving cutter with the gear blank in the proper relation in order to conform to the meshing action of the crown gear tooth to which the cutter corresponds. In other words spiral bevel gear teeth are generated or shaped by making the gear blank and

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rotary cutter roll together in exactly the same manner as if the cutter were a crown gear.

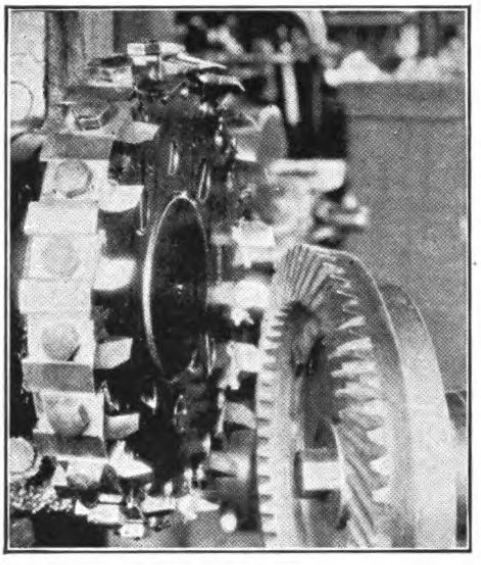


Fig. 207. Generating a Spiral Bevel Gear

The principle and the motions of the generating process are exactly the same as may be seen in the action of the more familiar machines for generating straight tooth bevel gears.

Hypoid Gears. — Hypoid gears are spiral bevel gears with offset axes. They have the advantage of permitting transmission of power between offset or non-intersecting shafts. Until the development of hypoid gears no successful method had been evolved for cutting teeth in bevel gears that were to run on offset shafts.

The tooth action of hypoid gears combines the rolling action of spiral bevel gears with some additional sliding, giving quiet operation and permitting the use of a low number of teeth.

These gears, used principally for automobile rear axles, have permitted lower drive shafts and consequently many major changes in design of the automobile body. They are finding use, also, in other places where the offset of the shafts is advantageous.

Helical Gears. — Helical gears (spiral gears) may be used to transmit motion between shafts that are either parallel or not parallel. They may be cut on either a milling machine, hobbing machine, or gear shaper. When the axis of the gears are at an angle they may then be called spiral gears, the action of the gear teeth is screwlike and owing to the narrow contact between the teeth these gears should be used for light service only. Their advantages are due to ease of manufacture and their quietness.

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When the axis of the gears are parallel, they then become helical spur gears where they have all the advantages of spur gears and can be substituted for spur gears if thought is given to the end thrust which is produced by the helix angle of the teeth. The tooth action in the plane of rotation is the same as spur gears with the added advantage that there is an overlap of teeth in the direction of the axis.

A single helical gear has either right- or left-hand helix while double helical or herringbone gears have right- and left-hand helices.

Hobbing Process. — Automatic gear hobbing machines are used to generate spur, spiral and worm gears. Fig. 208 shows

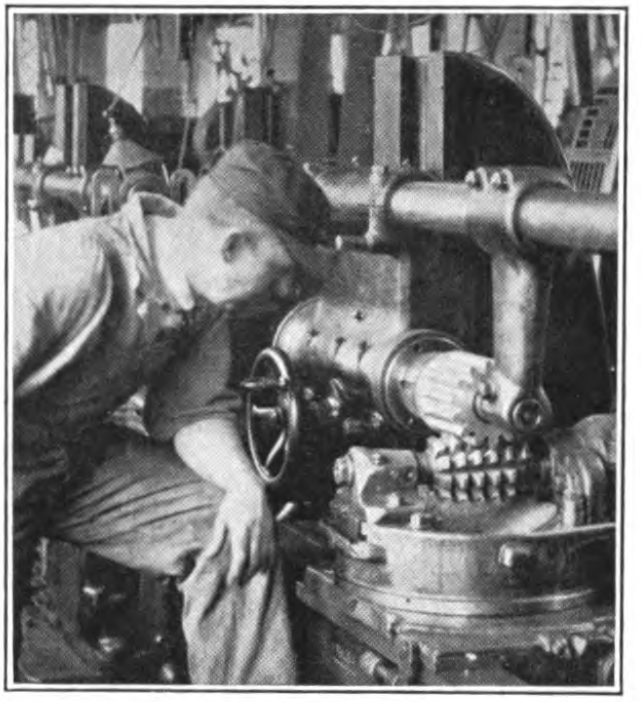


Fig. 208. Hobbing a Spur Gear on a Hobbing Machine

a machine manufactured for cutting spur and spiral gears. In hobbing gears a hob, see Fig. 209, is used instead of a formed cutter and the gear blanks are mounted on the work spindle or mandrel. They are not indexed after each cut but, instead,

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gear blanks and hob rotate together with a definite ratio of velocity. The velocity ratio is determined by the number of teeth in the gear and number of threads in the hob.

In the case of a single threaded hob one revolution of the hob



Fig. 209. Spur Gear Hob

is accompanied by a movement of the gear blank through a distance equal to one tooth. The change gears are arranged to furnish this ratio between the revolutions of the work spindle and the hob spindle. When the hob has completed the gear it has generated correct involute teeth.

The Hob. — The hob for spur or helical gears may have as many as three threads for roughing, but for finishing, a single thread hob is generally advisable. For high grade work, ground form hobs are generally used. One hob of a given pitch is sufficient for all numbers of teeth of spur and spiral gears within the capacity of the machine. When hobbing spiral gears, however, it is advisable to use a right-hand hob to cut a right-hand gear and a left-hand hob to cut a left-hand gear.

Hobs are usually made of high speed steel. A 29° or 40° threading tool or cutter is used to produce hobs of the standard pressure angles of 14 1/2° and 20°. The hob may be "gashed" or grooved in a milling machine. The teeth are radially relieved or "backed off" on a special machine or on a lathe furnished with a relieving attachment.

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After being hardened and tempered the hob is sharpened. If the hob is to be used on work where a high degree of accuracy is required it should be ground on the form of the teeth. Such a hob is known as a ground hob.

(*Note:* For a more detailed account of hobbing and hobbing machines we recommend a handbook entitled " Construction and

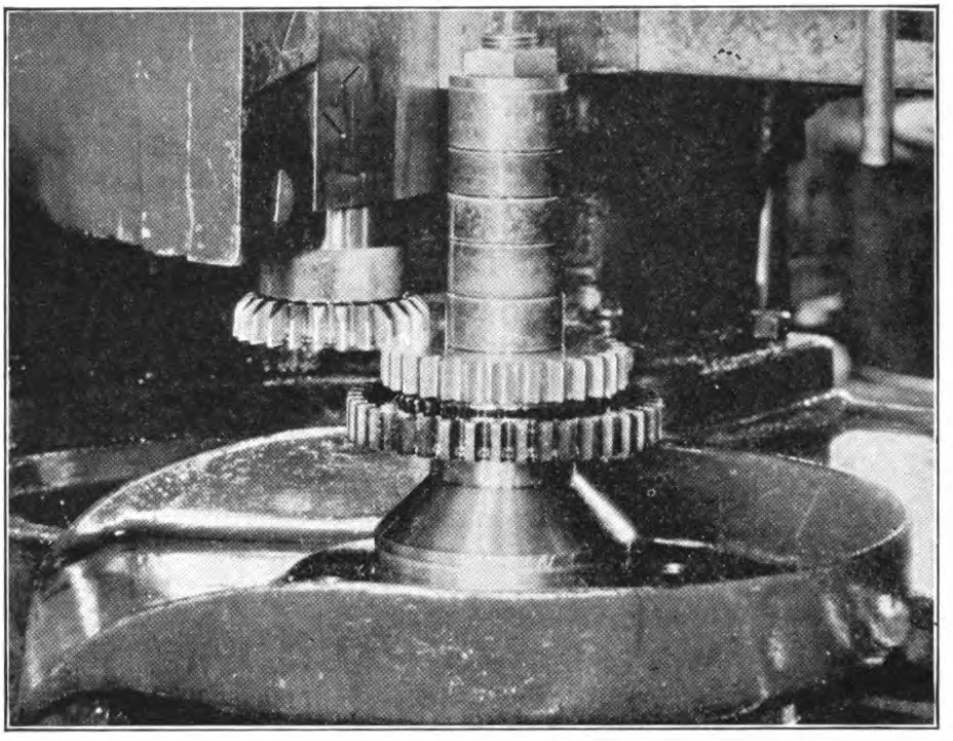


Fig. 210. Gear Shaper Operation

Use of Gear Hobbing Machines," listed at the back of this book.)

The Shaping Process. — Figure 210 shows a spur gear being generated by the shaping process. Internal gears, quill or cluster gears, spiral gears, sprockets, ratchets and cams may be cut satisfactorily in this way. The cutter is of a special form, and it is carried on the end of a ram which reciprocates vertically.

The gear blank is put on a vertical spindle so that it lies in a horizontal plane. Feed takes place as the head, carrying the ram, travels along the cross rails. In this way the cutter may be fed straight into the blank until it reaches the proper depth,

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whereupon by an arrangement of change gear and index mechanism, the work and cutter are rotated in unison, similarly in all respects to the meshing of two gears. The teeth of the cutter, by this rotary movement, generate the required shape of the

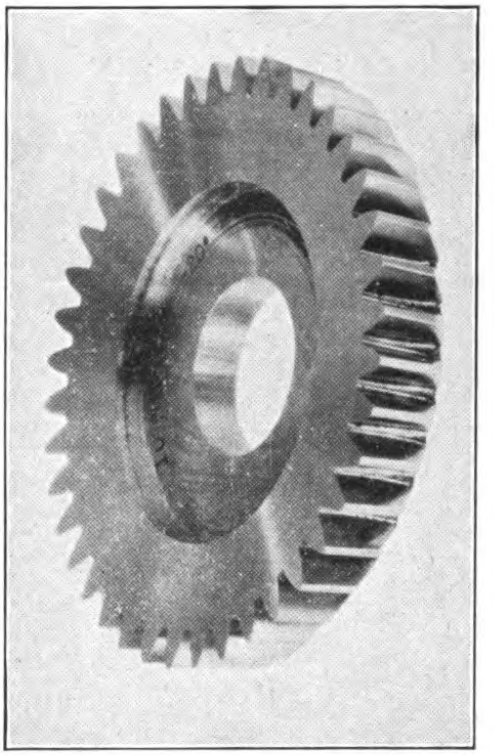


Fig. 211. Gear Shaper Cutter

gear teeth. The chip is taken on the downward movement, although by an adjustment of the machine and by reversing the cutter the chip can be taken on the upward movement.

The Shaper Cutter. — One cutter only is required for each pitch to the full capacity of the machine, Fig. 211. It is usually made of high speed steel and resembles a spur gear in the outline of its teeth.

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CHAPTER X

The Screw Machine

The screw machine is a further development of the engine lathe, so designed that it presents with a high degree of rapidity a series of tools to the part or stock held in the chuck and upon which several operations are to be performed. It differs from the lathe in that it is provided with a front and rear cross slide and the tail stock is replaced by a slide on which is mounted a turret. This turret is provided with several tool positions which can be indexed into a working position as the slide is advanced, permitting each tool in succession to perform an operation on the part being turned.

Screw Machines may be divided into three general classes. First, the Turret Lathe or Plain Screw Machine designed primarily to handle work such as small castings and irregular shaped pieces or bar stock previously cut in short lengths. Second, the Wire Feed Screw Machine, which may be termed semi-automatic in operation, in that the feeding of stock and the operation of turret and cross slide, is controlled by a pair of levers. Higher rates of production can be obtained on these machines. They require, however, the constant attention of the operator to manipulate the operating levers. The Wire Feed Screw Machine is, in general, used for production from bar stock. The third class comprises the Automatic Screw Machine, which is designed for the production of large quantities of similar parts and is entirely automatic in its operation. That is, when once the cross slide tools, turret tools and controlling cams are set up and the machine is put in operation it automatically advances the stock or chucks a casting, indexes the turret and performs all other operations required to complete the part. The operator, when once the machine is started, has only to

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replenish the stock as it becomes exhausted. One operator can accordingly take care of two or more machines, depending somewhat on the nature of the part being produced.

Automatic Screw Machines are of two types, single and multiple spindle. The Single Spindle Machine feeds a single piece of

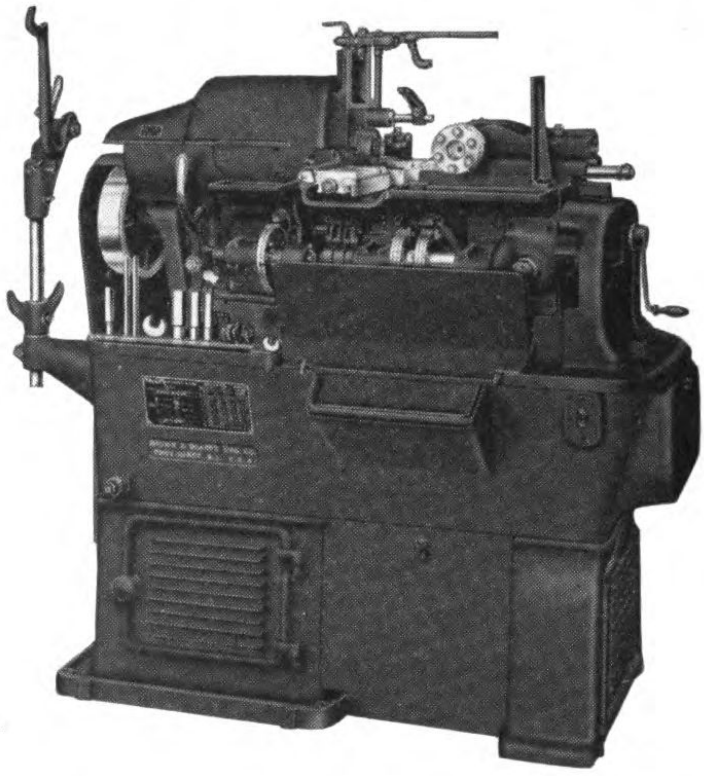


Fig. 212. Automatic Motor Driven Screw Machine

stock which is machined in succession by each tool in the indexing turret. The Multiple Spindle Machine feeds a number of pieces of stock. The spindles index so that the stock in each spindle is carried and fed successively to each tool.

Screw Machines vary in size from those used in producing small screws and similar parts, such as are used in small articles and small machines, to the larger type machines which produce heavier parts, such as those used in automobiles and other larger machines.

The automatic screw machine, Fig. 212, was originally designed

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for the production of small screws and studs but its broad range of possibilities encouraged its use for an almost endless variety of work. In addition, secondary or special operations can frequently be performed by the use of attachments which further increase the production possibilities of the machine.

The general principles of the automatic screw machine are relatively simple and for purpose of explanation we will use one of the single spindle type as an example. A bar of stock is held firmly in a hollow spindle and rotated. The required tools for working on it are mounted in a circular turret, which is advanced automatically toward the end of the bar of stock so that each tool in turn can do its work. The turret is automatically indexed after each tool has completed its operation, bringing the next tool into the working position.

Two independent tool slides, which move at right angles to the spindle, also carry tools that are automatically brought into contact with the stock. The direction of spindle rotation can be reversed and the spindle speed changed automatically depending on the character of the operation being performed. After a piece of work is completed and cut off, the machine advances the bar and the foregoing cycle of operations is repeated. This is continued until the bar is consumed, whereupon the machine automatically stops.

Cutting lubricant must be used freely with automatic screw machines in order to avoid developing excessive heat and spoiling the work or tools. As very exacting demands are made on the machine, and it is expected to run continuously and to work to extremely close limits, it is necessary that it be well cared for. Accordingly, the operating parts should be kept free from any gummy coating of dried lubricant and chips or dirt. If neglected the machine will become clogged to an extent that will interfere with its proper operation. However, an occasional wiping is sufficient to keep it in clean condition.

Proper Selection and Use of Tools. — The success of the automatic screw machine, in producing work with a high degree of

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accuracy, well finished and at a very rapid rate depends, to a great extent, on the selection and setting of tools. The design of the machines is such that the tools can be simple in form and the careful construction of the machine parts permits them to be relied on, in the matter of alignments. Setting and adjustment of the tools can be quickly and easily accomplished, and the work can be held within fine limits with very little attention to the tools after the original setting.

As a rule, the selection of the best type of tool for an operation, while usually governed by experience, is not a difficult matter if the suggestions given in this chapter on the use of the tools are followed. Good finish, as well as accuracy, is lost, however, if the grinding and setting of the tools is not done in a painstaking way. The necessary adjustments have been made as simple as possible and should be easily understood; instructions are given in the following pages showing how the setting and grinding should be done under various conditions.

Experience in " tooling up " is advantageous, when setting up a job, and will be of great help on special or very difficult jobs. However the principles of the tools are simple, and one, even though unfamiliar with this type of machine, should be able to get good results by combining proper care and a study of the instructions.

Tools Available for Various Operations. — Owing to the wide variety of work produced on these machines a considerable number of different tools is used, as shown in Fig. 213. These illustrations will serve to indicate the general appearance and the names of the different types. The line of tools shown covers all ordinary requirements.

External Turning Tools. — Balance turning tools, plain hollow mills, adjustable hollow mills, box tools, swing tools and knee tools are all used in the turret. Centering and facing tools, pointing tools and pointing tool holders with circular tools are suited for operations on the end of the work.

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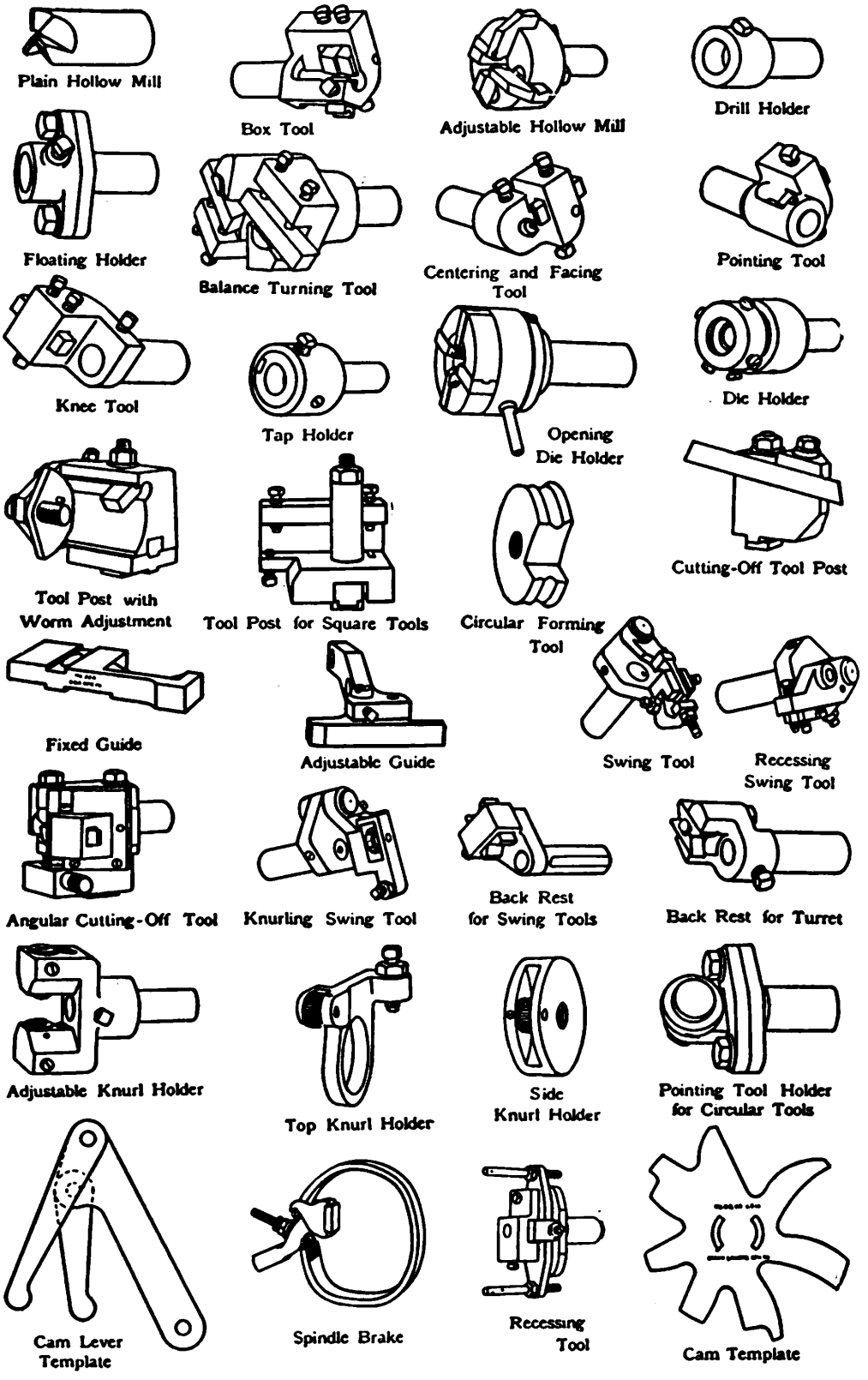


Fig. 213. Typical Tools for use on Screw Machines

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Internal Cutting Tools. — Drills, counterbores and reamers are held in drill or floating holders. Recessing swing tools are also used for internal operations.

Threading Tools. — Taps and dies, chasers mounted in opening die holders, and thread rolls held in cross slide knurl holders or in knurling swing tools are most generally used.

Knurling Tools. — Top and side knurl holders are used on the cross slides. For knurling from the turret adjustable knurl holders and knurling swing tools are used.

Forming and Cutting-Off Tools. — Circular forming tools and circular cutting-off tools are used on the regular cross slide tool posts and the tool post with worm adjustment. Square tools and thin straight blade cutting-off tools are used on the cross slides while the angular cutting-off tools are for use in the turret.

Supporting and Auxiliary Tools. — Swing tools, fixed and adjustable guides for operating swing tools, back rests for turret and spindle brakes add further to available equipment for use on screw machines.

General Suggestions on Selecting Tools. — The following very general suggestions should be supplemented by reference to the detailed discussion of each tool given in the treatise, " Construction and Use of Automatic Screw Machines," mentioned in list of publications at the back of this book.

The balance turning tool is the best all round tool for straight rough turning, with plain hollow mills and adjustable hollow mills, roughing style, as second and third choice.

For straight finish turning, box tools are preferable; adjustable hollow mills, finishing style, are sometimes used. The knee tool is only intended for turning scale on soft machine steel or machine steel.

On straight turning where the piece is long and very slender a pointing tool of the box type is better than any of the above tools as the bushing ahead of the blade holds the work steady.

For taper turning the swing tool is desirable and it is also

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applied on some form turning where the curve is long, very shallow and continuous, if circular form tools are not available.

As a rule, circular form tools are used on the cross slides for all form turning, and for straight turning behind shoulders, wherever they can be applied and the length of cut is not too great in proportion to the diameter. Extra wide circular form tools are held on the tool post with worm adjustment. If the turning cannot be otherwise handled, the swing tool may offer a solution.

Form turning may occasionally be done with a straight blade tool held in the tool post for square tools. This arrangement is seldom used however, as the tool has no advantages over the circular form tool and is short lived when compared with the circular type.

The tool which is usually best for centering the end to be drilled is a center drill clamped in a floating holder, as this permits easy adjustment.

If the stock stop is not used in the turret, or if for any other reason the end of the bar needs to be faced off as well as centered, a centering and facing tool which combines the two operations is used.

To round off, burr or point the end of work, where it is stiff enough so as not to spring under the operation, a pointing tool holder with circular tool should be chosen. After this is once shaped for the job it lasts indefinitely, as it can be ground without changing its form, and can also be set up easily because of the floating adjustment of the holder. If the piece to be pointed is slender and liable to spring, use a pointing tool of the box type, which supports the work just ahead of the cut.

Drills, reamers and counterbores should be mounted in a floating holder so they may be easily adjusted central with the work. A drill holder is not as suitable for this purpose, unless the tool used is so fine that it will spring enough to correct any inaccuracy in setting.

Cutting a groove or recess inside the piece is done with the recessing swing tool.

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Taps and dies should be held in non-releasing tap holders and die holders whenever possible. The releasing type is usually required only in cases where it is not possible to develop a thread lobe on the cam because of its slow movement, and the tool must dwell somewhat before backing out.

If a thread is to be rolled, the top knurl holder for the cross slide is often employed for carrying the thread roll, the cutting-off operation immediately following the threading operation on the same tool post. If the thread rolling operation is heavy the side knurl holder for the cross slide is better, as it is free from any tendency to pull up on the cross slide. If there is no room on the cross slide posts for the holders for carrying a thread roll, or if the thread is to be placed in such a position that tools on the cross slide cannot be used, then a thread roll in a swing tool can sometimes be used.

Thread rolling is often resorted to where the thread cannot be cut by a die, and should be undertaken only on brass, aluminum or similar soft metal. Frequently it is an advantage to roll short threads on these metals.

The opening die holder is used to take the place of the button die when the spindle is run in but one direction.

The adjustable knurl holder is to be preferred for knurling on straight work, because it carries two knurls which swivel for straight or diamond knurling and give a balanced cut. If the part to be knurled is not straight but formed, as convex for example, then the top or side knurl holders are employed. This also applies if the knurling is behind a shoulder. The knurling swing tool only applies on formed knurling or behind shoulders when the cross slide holders are not available, as discussed above under thread rolling. The top knurl holder is often preferable to the side knurl holder because it permits a cut-off tool to be used on the same tool post with it.

For straight cutting-off where no burring, rounding or forming of the bar or the cut-off piece is required a thin cutting-off blade of the straight type is used, held in a cutting-off tool post. The

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circular cutting-off tool is most frequently used because it can be shaped readily to properly part the piece from the bar, at the same time doing a chamfering or similar operation, and once formed retains its shape after repeated grindings. If the cut-off or back end of the work is to be pointed, or coned, use the angular cutting-off tool.

The fixed guide is intended for a pusher only, for forcing against the work the angular cutting-off tools, and various swing tools when they are not to be fed along the piece. If any swing tool is to be fed along the piece for turning after being forced into position by the guide, the adjustable guide should be used. This applies on either straight, taper, or formed work, because adjustment of the guide can compensate for any slight error or wear in tool or machine.

In cases where the cut causes considerable side pressure tending to spring the work, as in some thread rolling, knurling, or forming operations, a back rest should be used in the turret for support if the work permits. Swing tool cuts on slender work also require occasionally the use of a back rest in the swing tool shank. Do not use the back rests unless they are really necessary.

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CHAPTER XI

Miscellaneous Tools and Methods

Although in the foregoing pages we have discussed the fundamental machines; there are, however, many others that are developments from fundamental machines and designed for special purposes which, because of limited space, we cannot describe here. If the principles which govern the operation of the lathe, milling machine, drill press, planer, gear cutting and grinding machines are thoroughly understood, there will be no difficulty in understanding the principles of the others.

In this chapter reference will be made to several other important machines and methods of doing work.

Boring Machines are of two types: the vertical boring machine and the horizontal boring machine. (*Note:* Either or both types are sometimes called boring mills.)

The Vertical Boring Machine is particularly adapted for turning and boring heavy work that has a diameter large in proportion to its length. The revolving table is provided with T slots or chuck jaws for holding the work. The tools, similar to lathe and planer tools, are held in heads that feed up or down and across, supported by a cross rail as on a planer. In addition, some vertical boring machines have tool heads that feed in from each side. The work revolves on a table in a horizontal plane and the tools are stationary.

Very similar to the vertical boring machine is the vertical turret lathe which has, in place of a tool head, a turret with four or more positions for tools. It is used to bore, turn, face, ream, tap and thread. The turret revolves in a vertical plane as each tool is brought into position to perform its operation. In addition, the turret can be fed up or down, and across by means of the cross rail. An auxiliary head on the side performs the same

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operation that a similar head does on a vertical boring mill or planer.

On a Horizontal Boring Machine the work is set up on a horizontal table provided with T slots. The tool is set in the horizontal boring bar and the work can be bored, reamed,

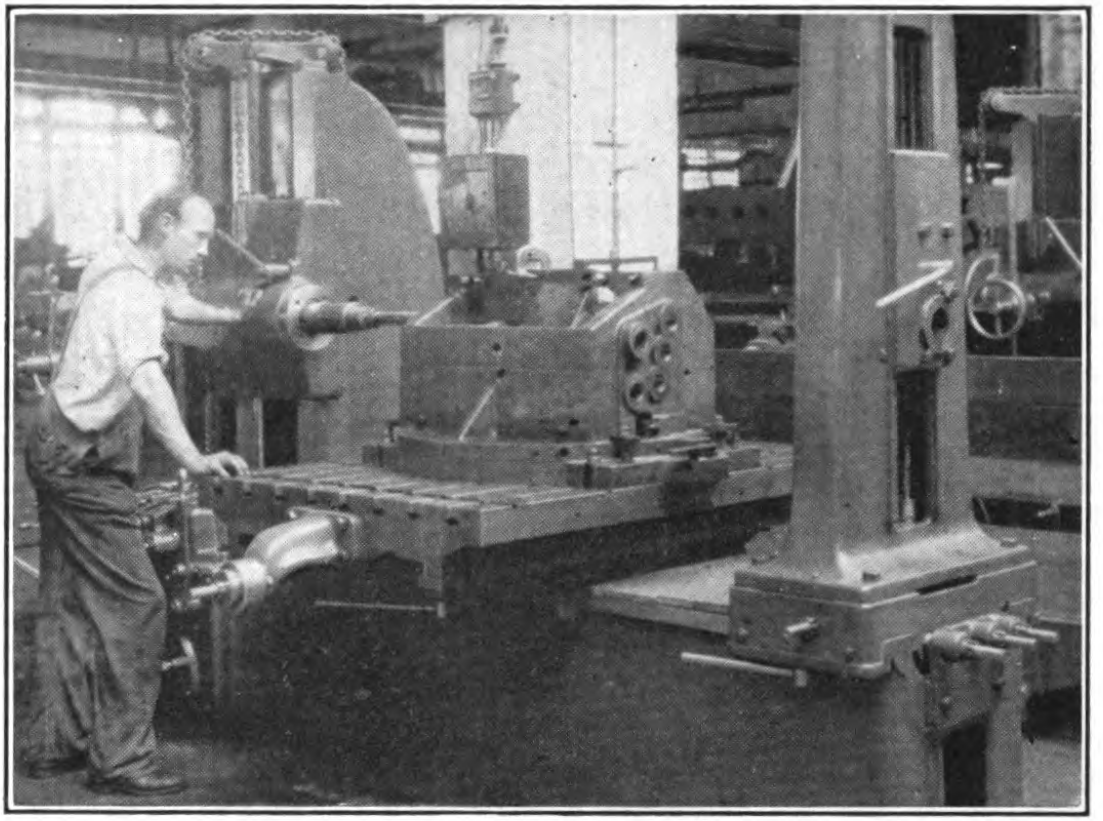


Fig. 214. A Horizontal Boring Machine showing a casting held in a Fixture and being Bored

counterbored or milled. This type is more satisfactory for boring and facing and where there are no turning operations to be done. Some types have a sliding spindle head and tail block; others have a fixed spindle head and tail block but with a table that can be raised and lowered.

The Broaching Machine is used for producing square, hexagonal, and irregularly shaped holes. To begin with, for broaching holes, the pieces must be either drilled, punched or cored. The broaching bar has teeth cut on it that resemble in

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cross section the shape of the hole required. The bar is drawn through the hole in the work and in the course of the operation each tooth takes a chip from the work until the end of the bar is reached and the hole is up to size. The end of the bar that begins the cut is tapered backward and each successive tooth is

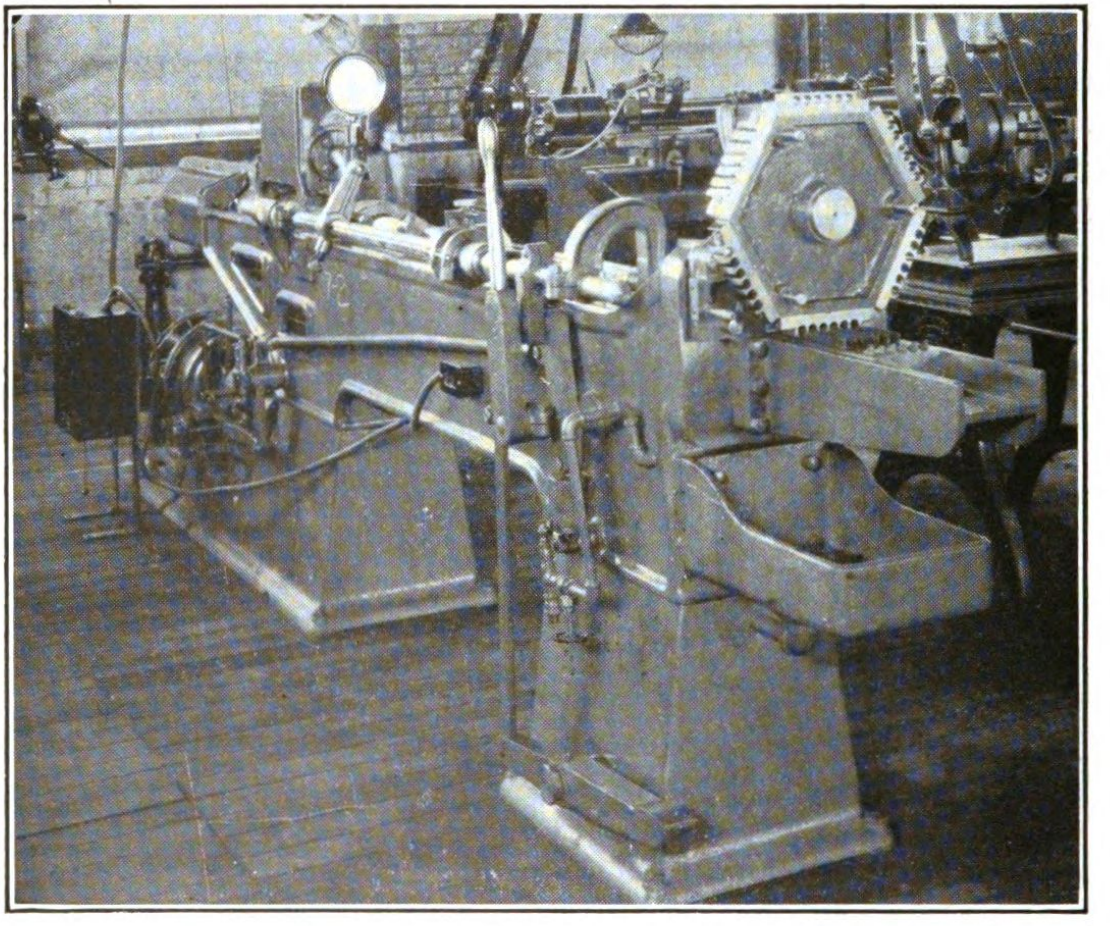


Fig. 215. Broaching Machine arranged with Special Indexing Fixture for Broaching six pieces simultaneously

from .002″ to .005″ larger than the tooth preceding it. At the large end of the bar there are a number of teeth exactly to the size of the desired hole. For the production of holes that are not round and for cutting splines and keyways the broaching process is very economical.

In recent years round holes also have been broached accurately in place of being reamed and this practice is growing. While the

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broaching of round holes was originally confined to milder metals, its use has been extended so that holes in other and tougher metals can be broached advantageously.

Also, some surface operations, particularly in automotive work, with two or more surfaces on different planes, are now being machined satisfactorily by broaching.

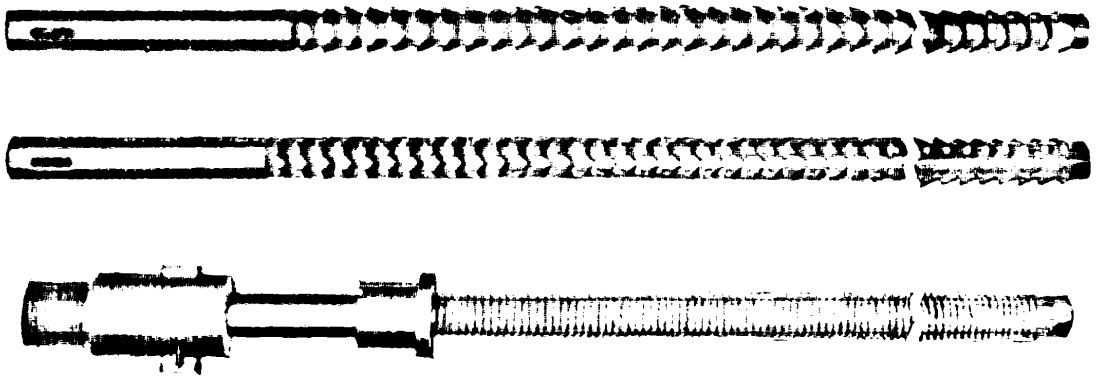


Fig. 216. Representative Broaches

The Slotting Machine is very similar in its action to a shaper, except that instead of planing horizontally it planes vertically. The work is bolted to the slots of a circular table and the ram with a tool at the end reciprocates vertically, taking a chip on the down stroke. The table feeds the work to the tool automatically after each stroke. Slotting machines are particularly useful for cutting splines and slots and planing work with a rounded outline.

Stamping Machines are used to perforate or blank out work from sheet metal. This operation is often called press work. Punches and dies are used to regulate the size of the work. The punch fits into the die with very slight clearance and the size of the hole desired determines the size of the punch, and the size of the blank required determines the shape and size of the die. In the process, the sheet metal, either in the form of strips or sheets, passes under the punch and over the die. Pressure from the stamping machine or press forces the punch through the metal and into the die, with the result that a hole is

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produced and a blank is made. The die is made of hardened steel and tempered to suit the nature of the work. The punch is fitted to the die, given proper clearance and hardened. Punches

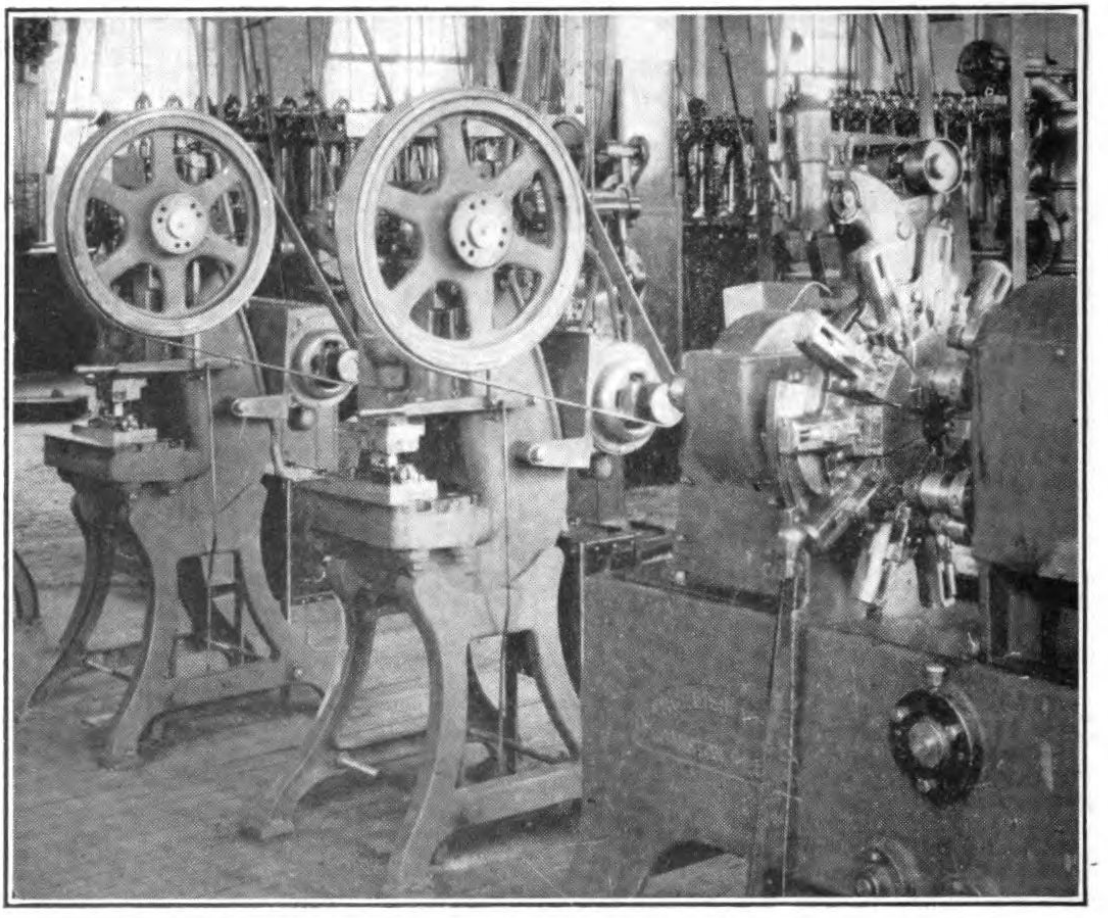


Fig. 217. Motor Driven Stamping Presses. Machine at right is a Special Index Drilling Machine

are generally made of different alloys, high speed steel and non-changeable oil hardening steels. Dies are sometimes used without lubrication but they last longer if the stock is oiled slightly. Blanking dies have an angular clearance of from 1° to 2°.

Stamping Presses are also used with forming dies to form sheet metal into various shapes. Sometimes this is done with cold sheet metal and sometimes with the metal at a malleable heat.

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Swaging is a process for shaping metal while it is cold by successive blows of a hammer. A swaging machine is provided with a die that is used to produce the desired form. By this method cold metal can be reduced in diameter or drawn out in length.

Lapping is a form of refined grinding. It is resorted to for final finishing of either hardened or unhardened work, particularly where smooth finish and extremely accurate size are desired.

Tumbling is the process whereby small parts are cleaned or given a desired surface finish. A " tumbling " barrel is used and it is rotated by mechanical means. Sawdust, beach sand, soda water or some other cleaning agent may be used, depending on what result is desired.

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CHAPTER XII

Electrical Motors and Controls

With the rapid increase in the use of individual motor drives and control equipment for machine tools it has become desirable for the young machinist to have a general understanding of the operation of this equipment. More and more, electrical devices, Figs. 218 and 219, are taking the place of complex mechanical ones, performing such natural functions as reversals, speed changes, movements, braking and other operations. It is beyond the scope of this chapter to cover a detailed description of the common motors and devices used, but many books are available covering this subject completely.

Power Supply. — Electric currents used for power are direct current, D. C., and alternating current, A. C. A direct current system's voltage remains at a constant value and the current flows in one direction only. Its use is gradually disappearing due to high transmission and equipment costs.

Direct current is necessary for certain purposes however, as it has the particular advantage of easily permitting adjustable speeds in motors. Usually when it is used, the direct current is obtained from a direct current generator driven by an alternating current motor. Very little direct current is furnished by power companies, due to the above mentioned transmission costs.

In an alternating current system, the voltage changes continuously in value from a maximum in one direction to a maximum in the opposite direction. The current, also, changes to these two maximums. The rate at which the reversals of the voltage and current occur is called the frequency and is measured in cycles per second. A cycle is one complete alternation of the voltage or current. Common frequencies are 60, 50, and 25 cycles, the former being in most common use in this country.

In transmitting electricity, the amount of power being trans-

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mitted is proportional to the product of the voltage and the current. Therefore, the higher the transmission voltage, the less the current for a given load and consequently the smaller the conductors can be in cross section. It is economical to transmit large amounts of power at high voltages, such as 110,000 volts, and to distribute this power to the consumer at different voltages such as 110, 220, 440, 550 and even 2200.

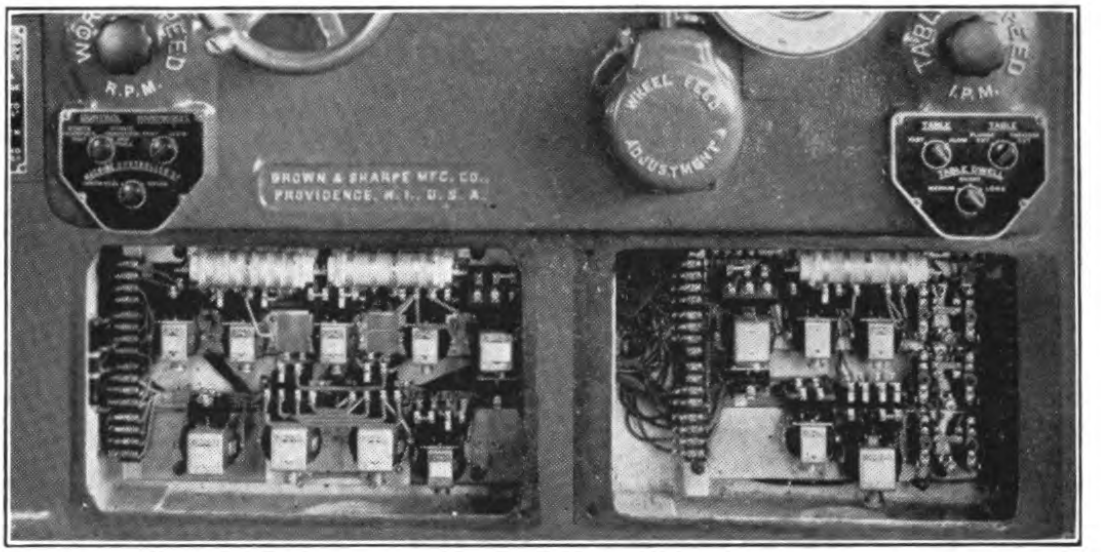


Fig. 218. Direct Current Controls on Brown & Sharpe Grinding Machine

When alternating current is used it is possible to make voltage changes by means of transformers. Direct current cannot be transformed from one voltage to another without the use of expensive machinery.

For reasons of economy, alternating current is rapidly replacing direct current for both industrial and domestic power.

Direct Current Motors. — There are different methods of winding direct current motors and connecting the fields and these methods result in three types of direct current motors which have different operating characteristics. These are known as series, shunt and compound motors. The expensive control apparatus necessary for direct current motors and the high maintenance cost have proven disadvantageous.

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Series Motors. — The series wound motor, Fig. 220, has the field winding connected directly with the armature and in series with it. The speed of this type of motor varies considerably with the load and is classified, therefore, as a variable speed motor and used where a constant speed is unnecessary.

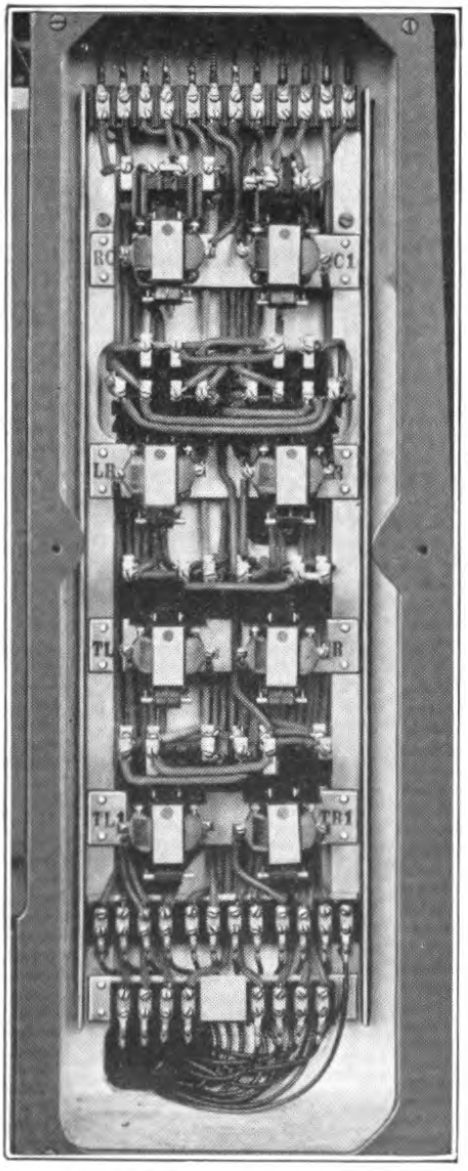


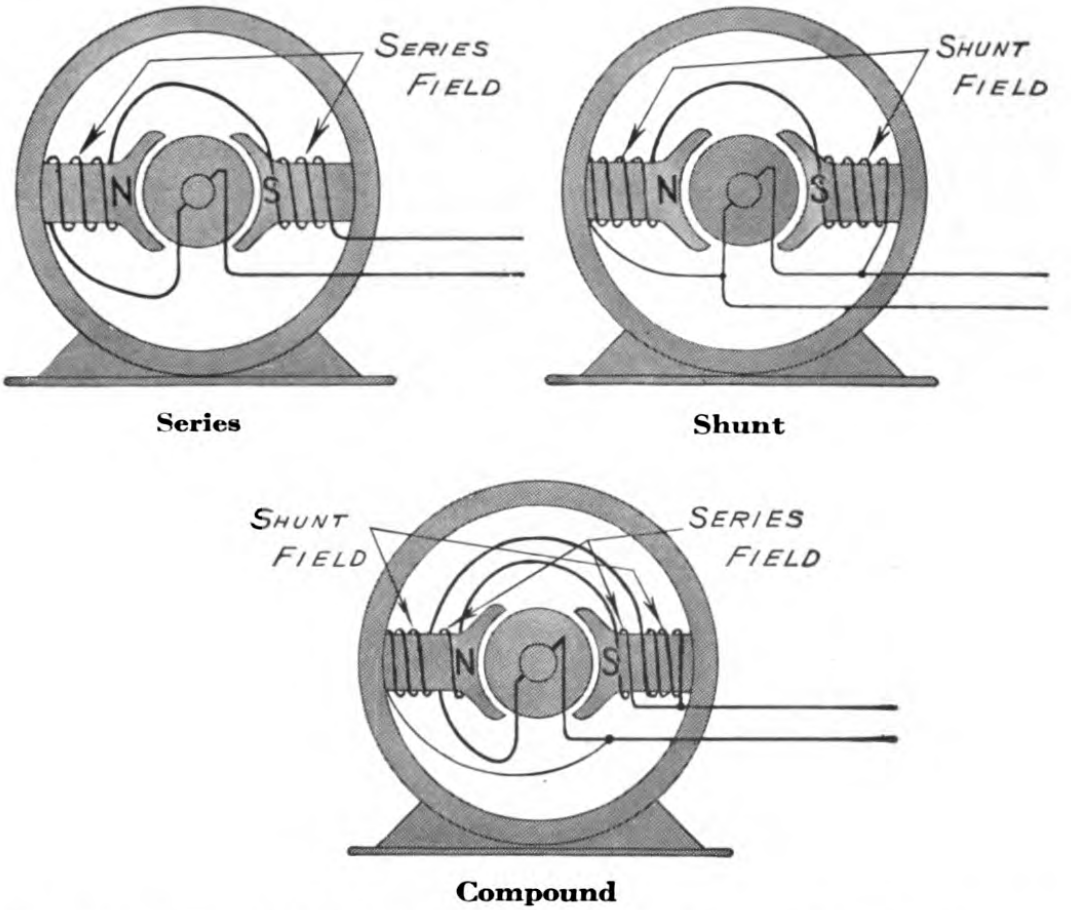
Fig. 219. An Alternating Current Relay Panel on Brown & Sharpe Milling Machine

The torque or turning effort of a direct current motor varies directly with the strength of the field and the armature current. When a heavy load is placed upon the motor, the speed drops but there is an increase in the armature current which also passes through the field winding of a series motor and the torque increases. If the load is light the speed increases excessively and even dangerously and damage may result to the motor if the load is removed. Due to this danger a series motor should be positively connected to its load so that it may not accidentally "run away."

Shunt Motors. — A shunt wound motor, Fig. 220, has the field winding connected directly to the line, independent of the armature. This type of motor runs at a constant speed despite the load fluctuations. It does not, however, have the powerful starting torque of the series motor.

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Compound Motors. — Compound wound motors, Fig. 220, incorporate both the series and shunt windings and so obtain the desirable characteristics of both. Speed changes occur but are not as wide with compound motors as with series motors. The compound motor should be used where the line voltage fluctuates suddenly and widely.



Series Shunt Compound

Fig. 220. Three Methods of Winding Direct Current Motors

Alternating Current Motors. — Alternating current motors are inherently constant speed motors, the speed being dependent on the frequency of the current supply. The speed may be adjusted, however, by the use of expensive auxiliary equipment.

Squirrel Cage Induction Motors. — The most widely used alternating current motor is the standard squirrel cage induction motor, Fig. 221. This type of motor has the magnetic field in

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the rotating member of the motor induced by currents flowing in the stationary member. The rotor does not have any connections to the line.

The motor has simple, reliable construction and good operating characteristics and can be obtained with many types of motor enclosures that enable it to operate under many adverse

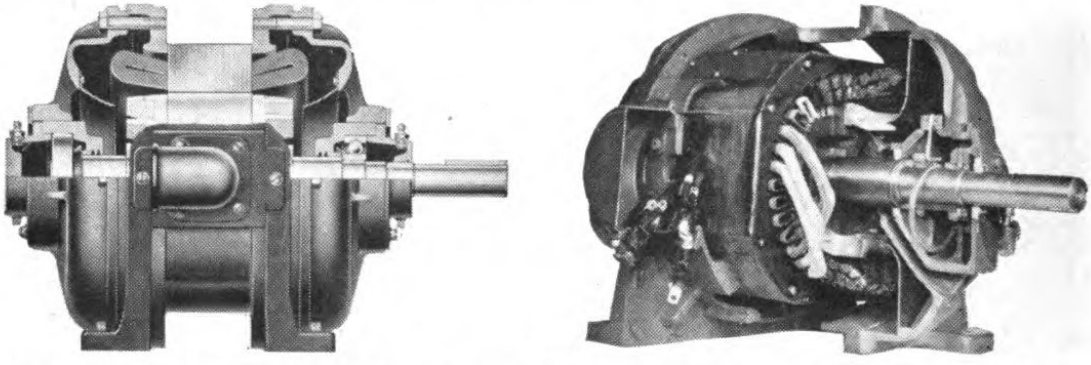


Fig. 221. Standard Squirrel Cage Induction Motors, at left Ball Bearing Type and at right Sleeve Bearing Type

conditions. The motor enclosure's name is descriptive of its type such as the open, semi-enclosed, totally enclosed, totally enclosed fan cooled, splash proof and explosion proof.

Synchronous Motors. — Another type of alternating current motor is the synchronous motor which rotates at the same speed as the alternator that supplies its current or at a fixed multiple of that speed. A simple rule for finding the speed is to divide the frequency in cycles per minute by the number of pairs of poles, the quotient being the revolutions per minute or:

Letting:

F = Frequency

P = Number of pairs of poles

$$\text{R.P.M.} = \frac{60\ (\text{F})}{\text{P}}.$$

Starting Torque of a Motor. — The starting torque of a motor is the effort which the motor develops when full voltage is applied to the armature winding. The torque of an induction motor can be controlled through proper design of the rotor winding or bars by changes in their resistance and location.

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Lubrication of a Ball Bearing Motor. — The lubrication needed for a ball bearing motor depends on the length of time the motor is in use and the conditions under which it operates. Most small motors are supplied with enough grease to operate under average conditions for a period of one or two years. In general, each time the grease is changed the bearings should be flushed out with alcohol, spindle oil, flushing oil or carbon tetrachloride. Carbon tetrachloride is excellent to use as it is a ready solvent of caked grease.

It is important that the correct amount of grease be put back in the bearing. Too much grease may cause the bearing to heat up and an excess may flow into the motor and damage the windings. Some motors have two fittings that allow the motor to be greased while in operation. One fitting is to allow the grease to enter the housing, while the second fitting allows an excess of grease to be released.

Dirt is the greatest enemy of ball bearings and care must be taken to prevent any dirt from getting into the bearing or the lubricant.

Application of Motors to Machine Tools

Motors are used on machine tools for a wide variety of purposes and applied or attached to the machine tool in several ways. The motor can be made integral with the machine, attached to it, made adjustable to the requirements of certain installations or it can be used as a drive for auxiliary equipment. The possibilities of the use of motors on a machine tool are entirely dependent upon the requirements, and location of the motor depends on good design. The type of motor selected depends on the type of work which the motor will be called upon to do.

The illustration, Fig. 222, shows a Plain Grinding Machine on which it will be noted how the grinding wheel is driven by one motor (A), the headstock, by another (B), and the coolant pump by a third unit (C). In addition there is a fourth motor (D) built into the machine to drive the table. Motors that

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are marked (B), (C), and (D) are totally enclosed motors, as they are operated where grit and water may be in the air, and there is need of protection for the motor. The motor marked (A) is an open type motor.

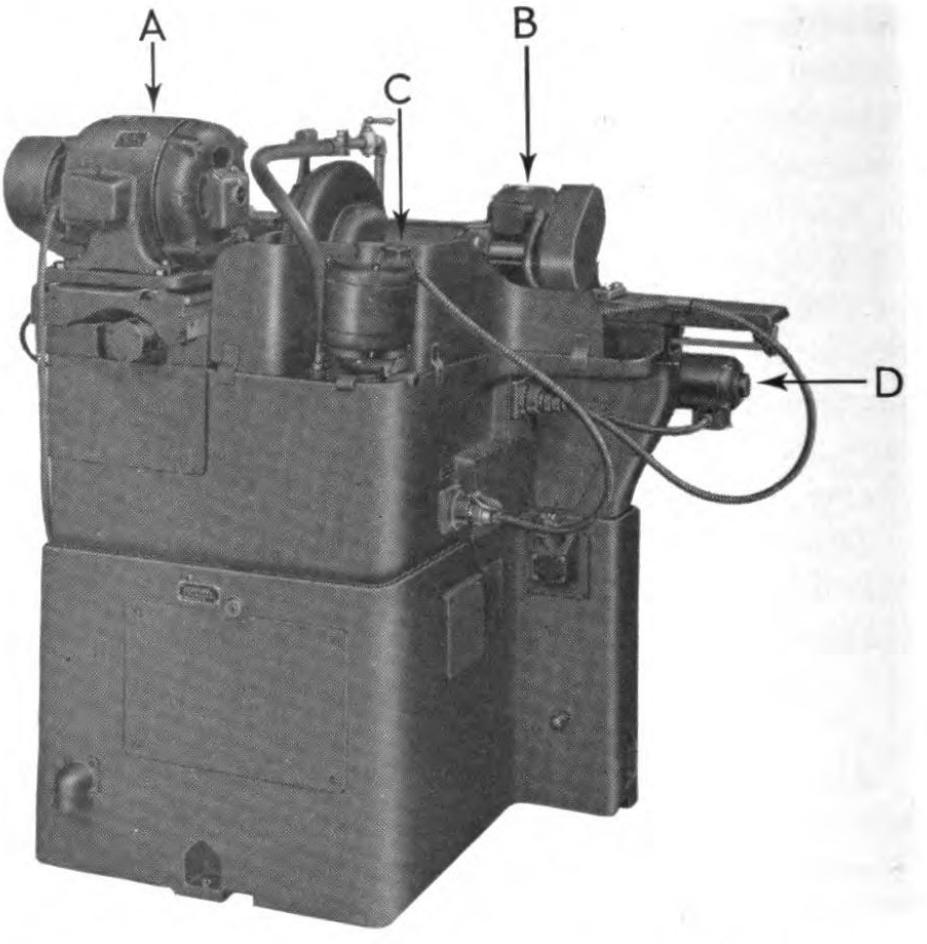


Fig. 222. Rear View of Plain Grinding Machine showing four motor installations

The ventilation of this motor is arranged to exhaust on the grinding wheel end thus insuring cleanliness of the air which is pulled in from the pulley end and is free from grit and coolant spray.

These motors are known as general purpose induction motors, and are designed and furnished for this particular kind of work by the manufacturer.

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If any of these motors are intended for rapid reversing service, consideration of this must be taken in their design and high resistance windings, or bars, should be used on the rotors. The rotor would also be made with lower inertia. Similarly, if any of these motors are used for only short periods of time during the operation of the machine, advantage could be taken of this to obtain a higher horsepower rating in the same frame or the same horsepower rating in a smaller frame size, giving rise to such nameplate stampings, as 5, 10, 15 or 30 minutes instead of " Continuous."

General purpose motors are always rated 40° Centigrade rise continuous, which means that they will carry their rated load continuously without exceeding a temperature rise of 40° C in a surrounding temperature of not more than 40° C. Speaking in terms of Fahrenheit in a room temperature of 70° F, the motor temperature could rise to about 140° F, which might give rise to mistaken alarm since it would be uncomfortable to touch. In case of doubt as to motor temperatures a thermometer should be used.

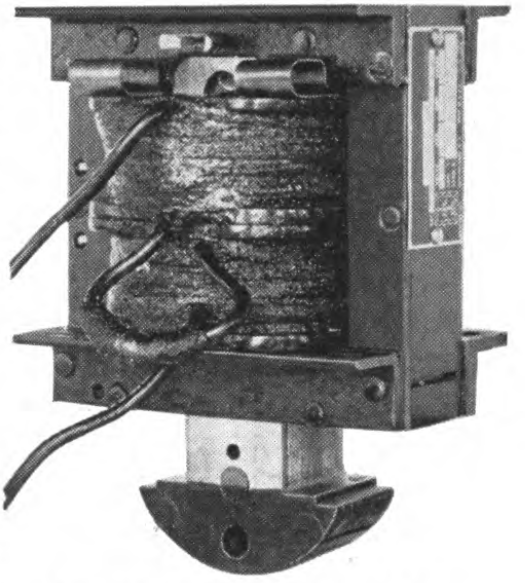


Fig. 223. A Solenoid

General definitions and descriptions of electrical devices follow.

Solenoid. — A solenoid, Fig. 223, is a wound wire coil which acts as a magnet and tends to draw a steel bar plunger into the center of the coil when energized by an electric current. As a rule the coil has a steel frame around it to increase the pull on the plunger. When the current is on, the armature of plunger is drawn into the coil, due to the magnetic pull. Springs, or the weight of the parts, pull out the armature when the current to the coil is shut off.

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Contactor — Relay — Magnetic Switch. — A contactor is a magnetic switch, Fig. 224, which opens or closes circuits leading to motors and other power apparatus. There is no difference in the principle of operation between relays or con-

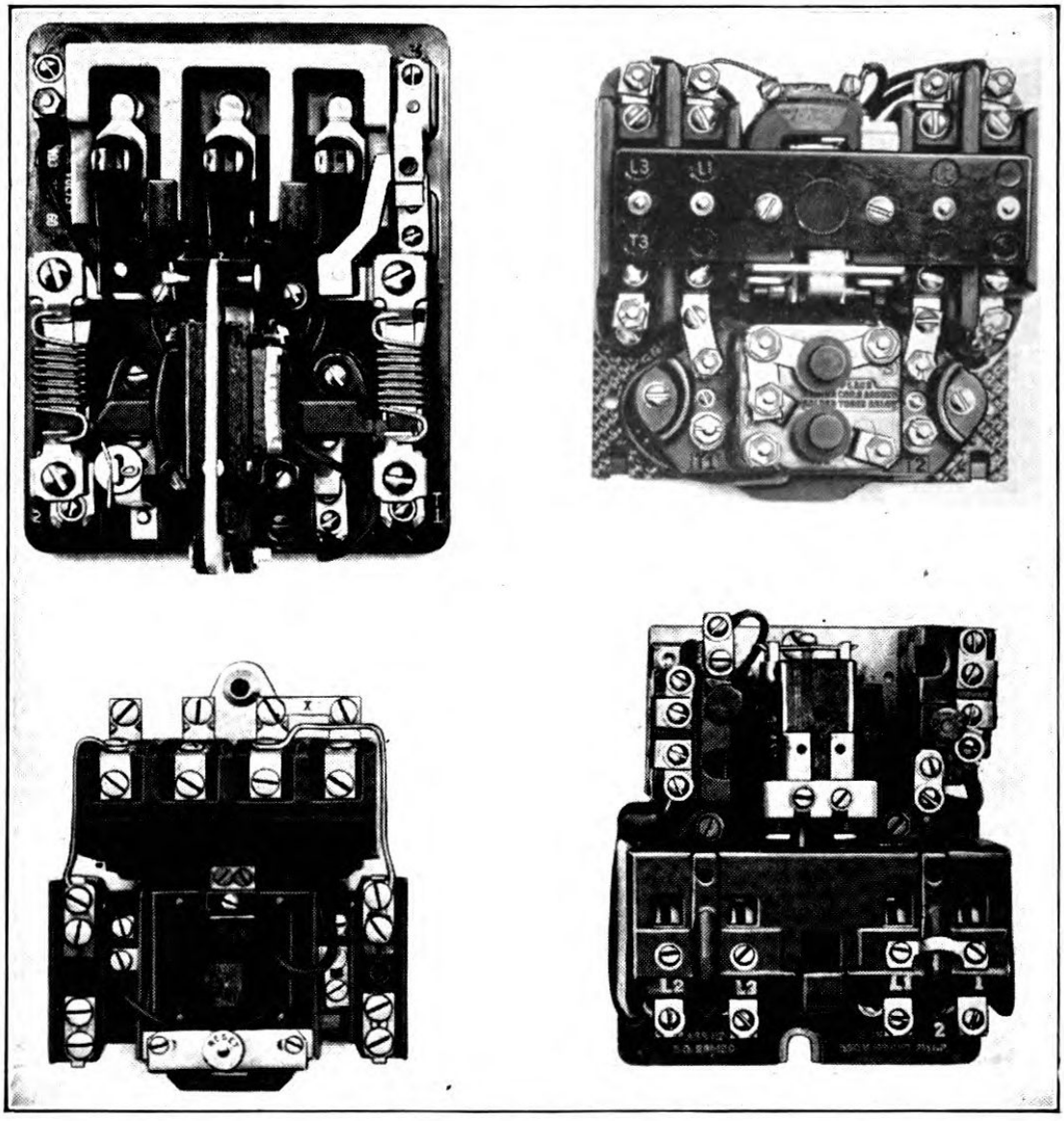


Fig. 224. Four Different Types of Magnetic Switches

tactors, except that as a rule the contacts on relays handle small currents while those on contactors have to transmit whatever currents are required by motors. Figure 219 shows a relay panel used on an Electrically Controlled Plain Milling Machine.

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Overload Relays. — Relays of this type, Fig. 225, are used to protect motors from currents which would overheat them. In general they use a heater coil with a fixed resistance through which the motor current passes. The relay contact in one type of switch is held in place by a pawl pressing against a ratchet

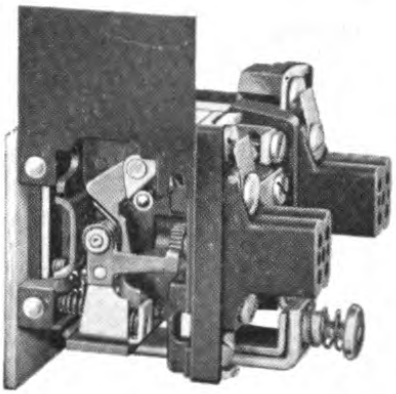


Fig. 225.
An Overload Relay

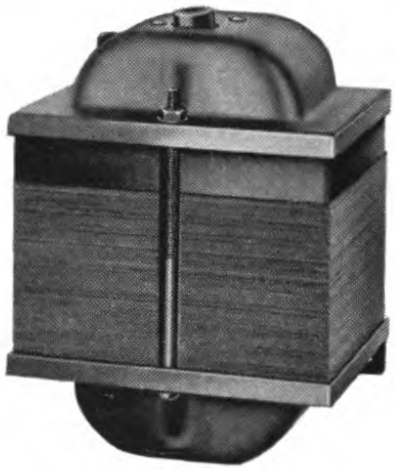


Fig. 226.
A Transformer

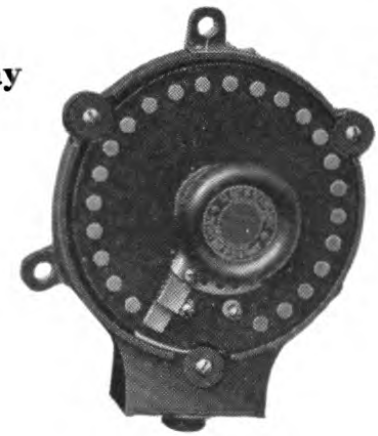


Fig. 227.
A Rheostat

wheel which is kept from rotating because of a soldered connection to its bearing. When the current in the heater coil exceeds the rated motor current, the heat generated in the coil melts the solder. The solder when melted lets a spring force open the contact as the ratchet wheel rotates. The opening of the relay contact deenergizes the coil of the switch connecting the line to the motor and opens this circuit. A reset button is used after

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the solder is cooled to close the relay contact. This compresses the spring and engages the pawl with a new tooth on the ratchet wheel. Some motors have overload protection, using heater elements built into a manually operated switch, instead of using overload relays.

Mechanical Interlock. — A mechanical interlock prevents one switch from going into contact until the other is released. This interlock is used between two magnetic switches where simultaneous closing of these two switches would cause a short circuit, such as forward and reverse switches on a motor.

Fuse. — A fuse is used as a protection against excessive currents such as would occur in short circuits in an electric circuit. Its purpose is to open the circuit.

Transformer. — A transformer, Fig. 226, is a device which makes possible the change of an alternating power supply from one voltage to another voltage. They are of extreme importance in the transmission of electric power, both for raising the generated voltage for transmission, and for reducing the high transmission voltages for consumption.

Rheostat. — A rheostat, Fig. 227, is an adjustable resistor by means of which the speed of a direct current motor may be controlled. One type has a coil of resistance wire with taps at different points. These taps are connected to a series of buttons, set in a circle on an insulated panel. A contact arm, pivoted at the center of this circle, can be set to contact any button thereby inserting any amount of resistance from zero to the maximum of the rheostat.

Switches. — A switch is any device which is used for opening or closing an electric circuit. There are many types of auxiliary switches available for different purposes, such as limit, selector, mercury and others. Fig. 228 shows the interior and exterior of a selector switch. The simplest type of switch known most commonly is the knife type which is used mostly to connect or disconnect power circuits to or from the source of supply.

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There are two general classes of push button switches. One type is the snap switch similar to the domestic light switch. By pushing the " ON " button the circuit is closed and remains so until the " OFF " button is pressed, which opens the circuit. This type of switch is used to a great extent on lighting circuits and the control of motors on domestic appliances and small

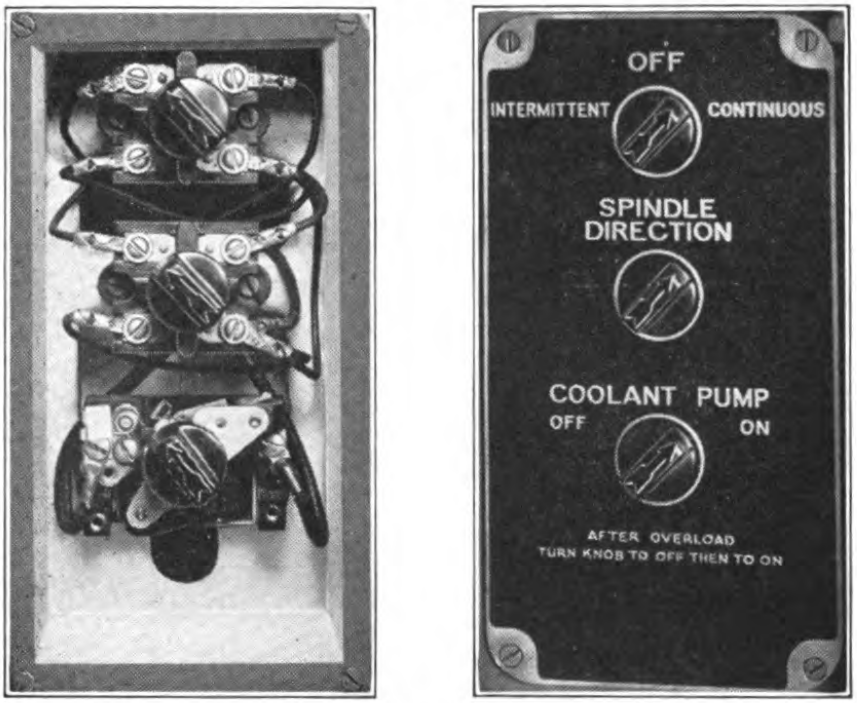


Fig. 228. Interior and Exterior of a Selector Switch

tools. This is known as the maintaining contact type.

The momentary contact push button is used as a means of indirect or remote control of motors and power circuits. The START button, when pressed, closes the circuit to the coil of a contactor causing it to operate. When the contactor operates, an auxiliary contact closes with other main contacts and closes an additional circuit to the coil, keeping it energized. The pressure on the starting button has been released and its contact opens again. The current that is holding the coil energized passes through the contact of the stop button which is normally closed. The STOP button pressed, the circuit is opened and the contactor releases.

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interchanging of connections is done by the motor contactor.

Plugging to a Stop. — When connections on a motor are suddenly reversed while it is going in one direction it will decelerate, pass through zero speed and accelerate in the opposite

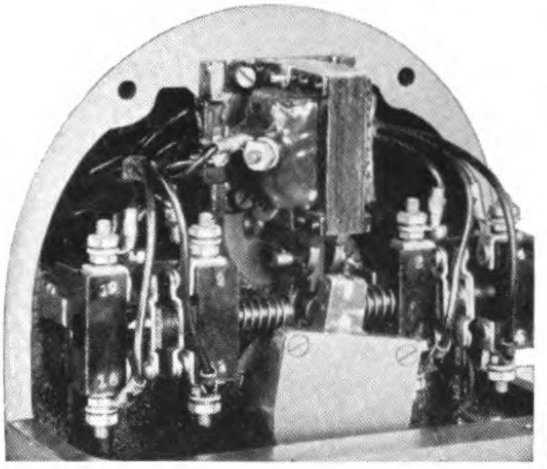


Fig. 230. A Plugging Switch as used on electrically controlled milling machine

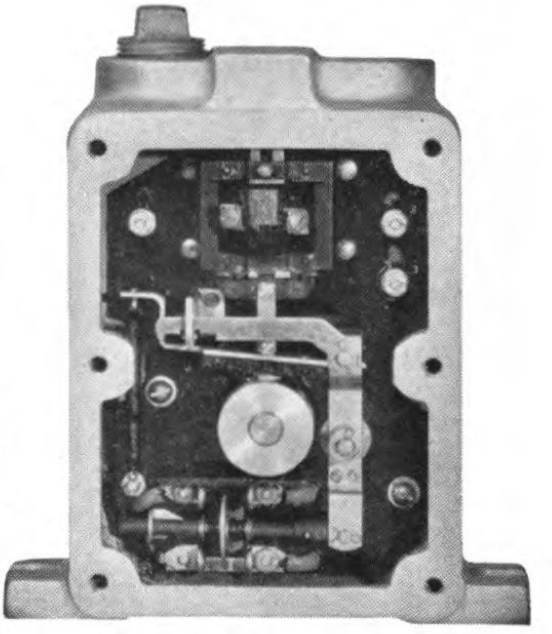


Fig. 231. A Commercial Type of Plugging Switch

direction. But if the motor was disconnected just as it reached zero speed it would be brought to a stop. This is known as plugging to a stop. The function of disconnecting the motor when it reaches zero speed is performed through the use of a plugging switch, Figs. 230 and 231, of which there are several types.

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CHAPTER XIII

Shafting, Pulleys and Belts

Shafting. — Shafting for the transmission of power to machine tools is made of steel. It is generally cold rolled steel and is obtainable at standard diameters or in diameters a little under standard.

Line shafting that is 2″ in diameter, running at 150 to 200 R.P.M. and supported by hangers bolted to timbers at intervals of not over eight feet, makes a good power transmission line. Couplings connect the lengths of shafting, and collars at each end of a bearing take care of the thrust and prevent end motion.

Pulleys. — A pulley may be solid or split; of cast iron, pressed steel, or wood. Solid pulleys are frequently used in places where there is little likelihood that they will be changed. Split pulleys are preferable on line shafts. To avoid excessive slippage it is better to avoid belting together pulleys that differ greatly in diameter. Pulleys may be attached to the shaft by either set screws or keys and split pulleys by clamp screws through hubs. Pulleys up to 36″ in diameter are ordinarily provided with set screws and those above 36″ with keyways and keys. High speed pulleys should be balanced. The faces of pulleys are usually " crowned " so that they will be higher in the center, in order to keep the belt in place. A belt always climbs to the highest point on the face of a pulley.

A style of pulley which is rapidly becoming more common is the V pulley for V belts. These pulleys may be for a single belt or for multiple belts of almost any number.

Generally such pulleys are of cast iron and must be machined accurately to the proper angle of V and one member of the combination must be adjustable for obtaining the proper belt tension as the belts are endless.

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Rules for Calculating Speeds of Shafts and Diameters of Pulleys

Diam. of driven $\times$ R.P.M. = diam. of driver $\times$ R.P.M.

Problem: Required, to find the diameter of a line shaft pulley to furnish the desired speed to a countershaft. Use the following formula:

Formula: Diam. of line shaft pulley = desired speed of countershaft $\times \frac{\text{diam. of countershaft pulley}}{\text{speed of line shaft}}$.

Data: Required speed of countershaft for machine is 200 R.P.M. Diameter of the countershaft pulley is 10″ and speed of the line shaft is 150 R.P.M.

Solve as follows: $200 \times 10 \div 150 = 13.3$.

Answer: Use a 13 1/2″ pulley on the line shaft.

Problem: Required, to find the diameter of the pulley for a countershaft that will furnish a desired speed to a machine spindle.

Formula:

Required speed of spindle $\times \frac{\text{diam. of spindle pulley}}{\text{speed of countershaft}} =$ Diameter of countershaft pulley.

Data: The required speed of the machine spindle is to be 1750 R.P.M. — the diameter of the pulley on the spindle is 6″, and the speed of the countershaft is 400 R.P.M.

Solve as follows: $\frac{1750 \times 6}{400} = 26\ 1/4$.

Answer: Use a 26″ pulley on the countershaft.

Problem: Required, to find the speed of a countershaft to give a desired speed for a constant speed drive.

Formula: Required speed of constant speed drive $\times \frac{\text{diam. of drive pulley}}{\text{diam. of countershaft pulley}}$ = speed of countershaft.

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Data: Diameter of the drive pulley is 12″ and the diameter of the countershaft pulley is 18″. The required speed of the constant speed drive is 750 R.P.M.

Solve as follows: $\frac{750 \times 12}{18} = 500.$

Answer: Speed of countershaft 500 R.P.M.

In order to find velocity of the last pulley in a layout of shafts or pulleys use the following rule:

Multiply together the diameters of all the drivers. Multiply this product by the speed of the first one. Divide this last product by the product of the diameters of all driven pulleys. The last result will be the velocity of the last pulley in the system.

Notes on Belts and Lacing

Belting may be of leather, rubber, or woven fabric; wire, rope, and chain are also used to transmit power. Rubber belts are used where moisture is to be expected, but they are not practicable when exposed to dust or oil. The suitable belt may be single or of multiple thickness depending on the diameter, width and speed of pulley and the power required.

Wherever leather belts are exposed to oil or dust and dirt they should be removed occasionally and cleaned in the following manner: first scrape to remove the accumulation of grease and dirt, then wash with gasoline. After drying, run through melted tallow which acts as a belt dressing and keeps the belt from drying and cracking.

The grain or smooth side of a belt should always run next to the pulley and whenever practicable, for the sake of greater contact, the belt should be applied so that the slack side is above and the driving side below the pulleys. The ends of a belt may be joined by lacing or hooks, and by gluing, cementing, or riveting. Laces for belts 2″ in width or less should be 1/4″ wide; for belts 2″ to 4″, 5/16″; 4″ to 16″, 3/8″; above 16″, 1/2″.

One of the first steps in lacing a belt is to make sure that the ends are cut square. To this end a try-square should be used

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to guide the knife. The holes should be made by a belt punch, and in a row, opposite each other.

Belts of light or medium weight should have a single row of holes in each end; belts less than 2″ in width should have two holes; 2″ to 3″, 3 holes; 3″ to 4 1/2″, 4 holes; 4 1/2″ to 6″, 5 holes. In the case of heavier belts a double row of holes is necessary in each end. On the ends of belts from 3″ to 5″ in width punch 3 holes for the lower row and 2 holes, staggered, for the upper row; from 5″ to 7″ have 4 holes and 3 holes.

To Lace a Small or Medium Belt. — Using the try-square, cut the ends of the belt square. In each end punch three holes

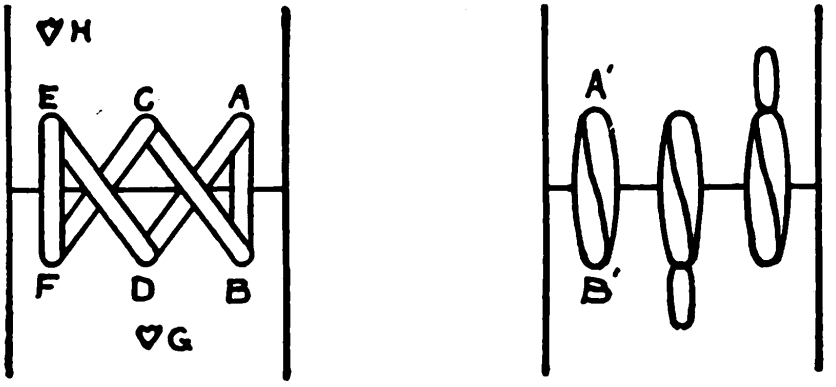


Fig. 232. Method of Lacing a Medium Size Belt

in a line, equal distances apart, 5/8″ from the end and 1/2″ in from the edge. With the rough side of the belt up, pass the ends of a 5/16″ lacing down through holes *A* and *B*. (See Fig. 232.) Have the smooth side of the lacing outward with the lace ends of equal length when they have passed through.

Pass end that went down through *A*, up through *B*. Do not pull tight. Pass end that went down through *B* up through *A*. Now pull tight. The lacing will appear on the pulley side as at *A′* and *B′*.

Pass end that comes up through *A* down through *D*, and end that comes up through *B* down through *C*. Pass end that goes down through *C* up through *D*, and end that goes down through *D* up through *C*. Draw tight.

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Pass end that comes up through *C* down through *F*, and end that comes up through *D* down through *E*.

Pass end that goes down through *E* up through *F*, and end that goes down through *F* up through *E*. Draw tight.

Punch small holes with an awl at *G* and *H* to fasten the ends.

Pass end that comes up through *E* down through *D* and up through *G*.

Pass end that comes up through *F* down through *E* and up through *H*.

Pull the lace tight through holes *G* and *H* and nick the side of the lace near each hole to form a barb. Cut off ends 5/16″ above the barb.

To Lace a Large Belt. — In preparing a large belt for lacing, two rows of holes for 3/8″ lacing should be punched in each end, four below and three above as shown in Fig. 233.

Cut ends square, using the try-square as recommended before.

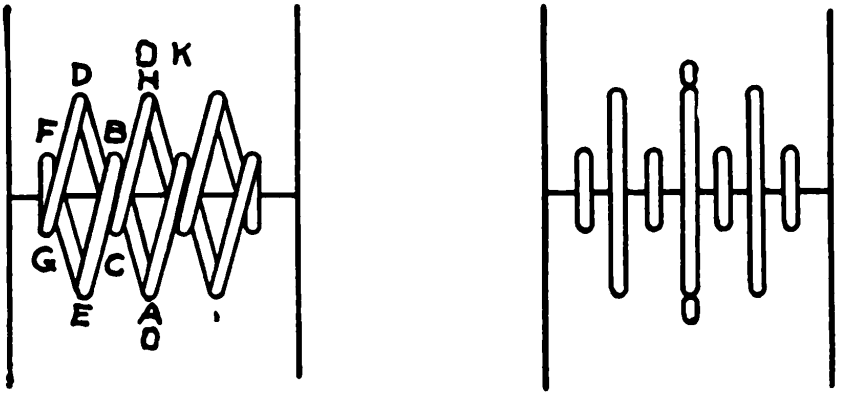


Fig. 233. Method of Lacing a Large Belt

Starting from the smooth side of the belt pass the ends up through *A* and *H*. Draw belt ends together and have lace ends of equal length.

With the end that comes up through *A* work to the left; down through *B*, up through *C*, down through *D*, up through *E*, down through *F*, up through *G*, down through *D*, up through *E*, down through *B*, up through *C*, down through *H*, and up through *K* Hole *K* is made to hold the end of the lace by its barb. In the case of very large belts it is advisable to have more than one

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hole to secure the end of the lace. A nick may be made in the lace wherever it passes through a hole. The right-hand side of the belt should be laced in a similar manner and it is better to lace belts of this size alternately.

To Measure the Length of a Belt. — Use a steel tape if there is one available or a piece of string. Pass it around both pulleys. By drawing the tape taut the measure can be obtained for a single belt. In case a double belt is to be used, add to the measurement *twice* the thickness of the belt. A twine measurement is satisfactory.

New belts usually stretch after being in use for a time. This increase in length, due to service, should be taken up when it becomes apparent; otherwise, the belt will slip and will not drive as it should. In the case of long belts, there is a way to anticipate the stretching by cutting the belt an inch shorter for every ten feet of its length.

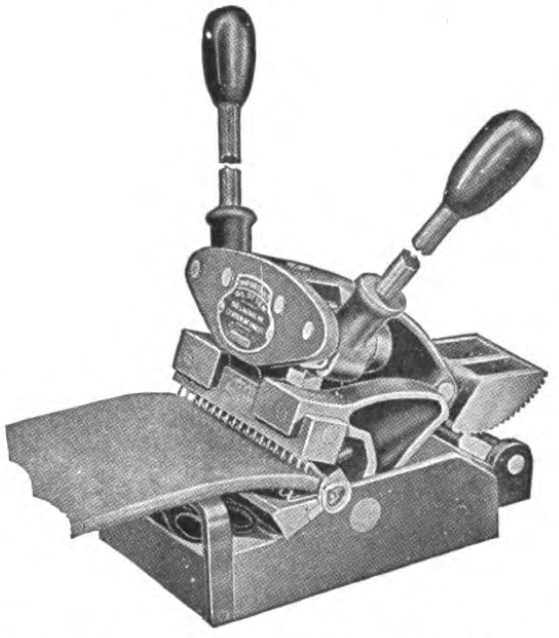


Fig. 234. One Type of Mechanical Belt Lacer

Rule for the Length of an Open Belt. — Multiply the *sum* of the pulley diameters in inches by 1.57. Add to this result the distance between the centers (in inches) multiplied by 2.

Letting

L = length of the belt in inches.

r = radius of the small pulley in inches.

R = radius of large pulley in inches.

D = distance between centers of shaft in inches.

A formula for finding the approximate length of a crossed belt is as follows: $L = 3.14\,(R + r) + 2\,D + \frac{(R + r)^2}{D}$.

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CHAPTER XIV

Toolmaking

This branch of the metal working industry is performed by a toolmaker who is a machinist possessing a greater knowledge of the trade than is ordinarily required to merely operate machines or make such parts of machines as may be the regular equipment or product of the shop in which he works. Toolmaking consists of producing special machines or parts of special machines, special apparatus, cutting tools, jigs, fixtures and various special gages used to obtain the correct size and shape of pieces to be made.

In this important work a toolmaker must show his mastery of the trade. It is essential to be able to work exactly and have some knowledge of drafting, enabling one to read accurately more complicated drawings than are ordinarily employed in the machine shop. One must be able to read and set fine tools quickly and accurately, for the greater part of the work will probably be confined to exacting measurements of one thousandth part of an inch or less. A knowledge of arithmetic and a familiarity with trigonometry is also essential, as the toolmaker, in laying out work, is continually called upon to figure angles and other measurements. The demands of toolmaking constantly test the ingenuity, accuracy, and thorough carefulness of the toolmaker.

The art of toolmaking is best acquired from experience. After completing an apprenticeship in the general shops, the apprentice machinist desiring to become a toolmaker practically starts another apprenticeship in the toolroom. Here the young toolmaker is first permitted to perform the more simple operations of toolmaking and, as skill and experience are obtained, is intrusted with more intricate work until such time as he is able to master any work that may come into his department. A good tool-

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maker is ever improving both his workmanship and his knowledge of tools and toolmaking, and it is only after many years of such work and study that he may consider himself an accomplished and " all-round " expert toolmaker

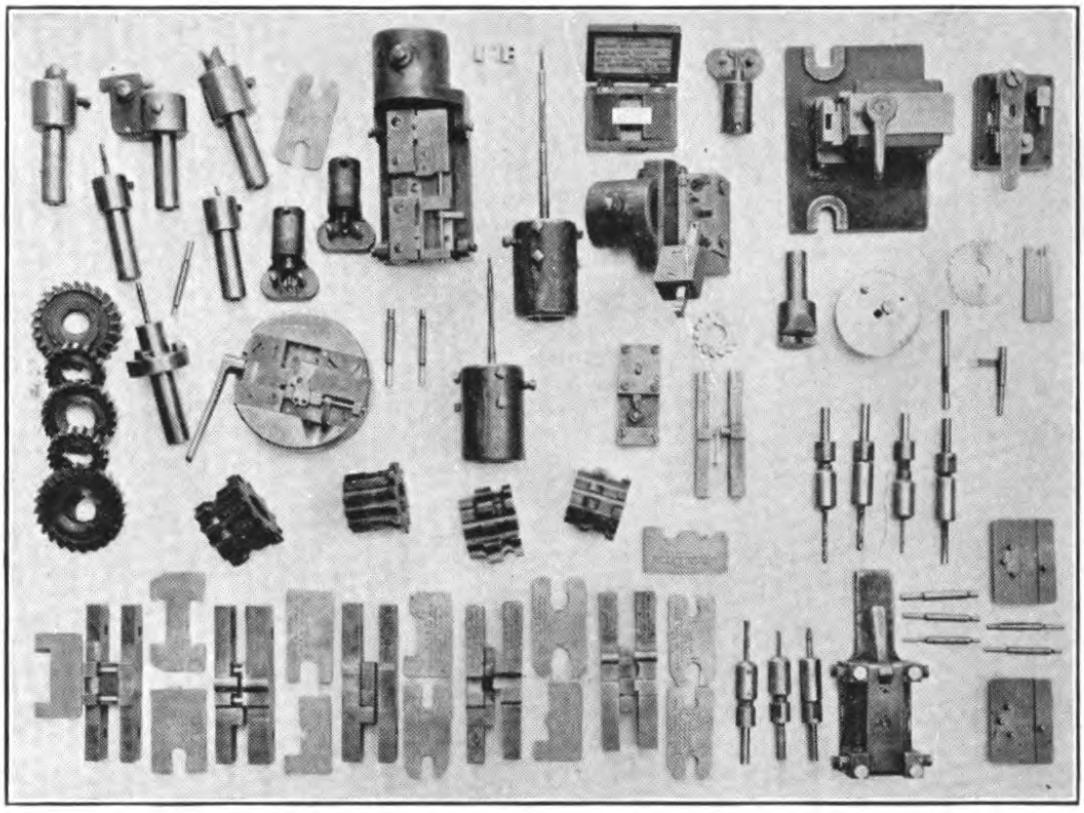


Fig. 235. Group of Special Tools made by Toolmakers including Special Tools of standard lines such as Milling Cutters and Drills made to order by the Manufacturer

It would be futile to attempt to treat comprehensively under one chapter the subject of toolmaking. The subject is too vast, and, inasmuch as there are numerous books published, treating on the various details of toolmaking, it is the purpose of this chapter to merely outline the work of a toolmaker.

Toolmaker's Kit. — The toolmaker takes considerable pride in his kit of tools. Almost invariably he will have a neat wooden or metallic case in which are fitted various drawers wherein is kept a well balanced assortment of tools. In addi-

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tion to the usual tools of the machinist there will be found Universal Bevels, Protractors, Steel Squares, Toolmakers' Knife-Edge Straight Edges, Vernier Calipers, both Micrometer and Vernier Height and Depth Gages, a Universal Surface

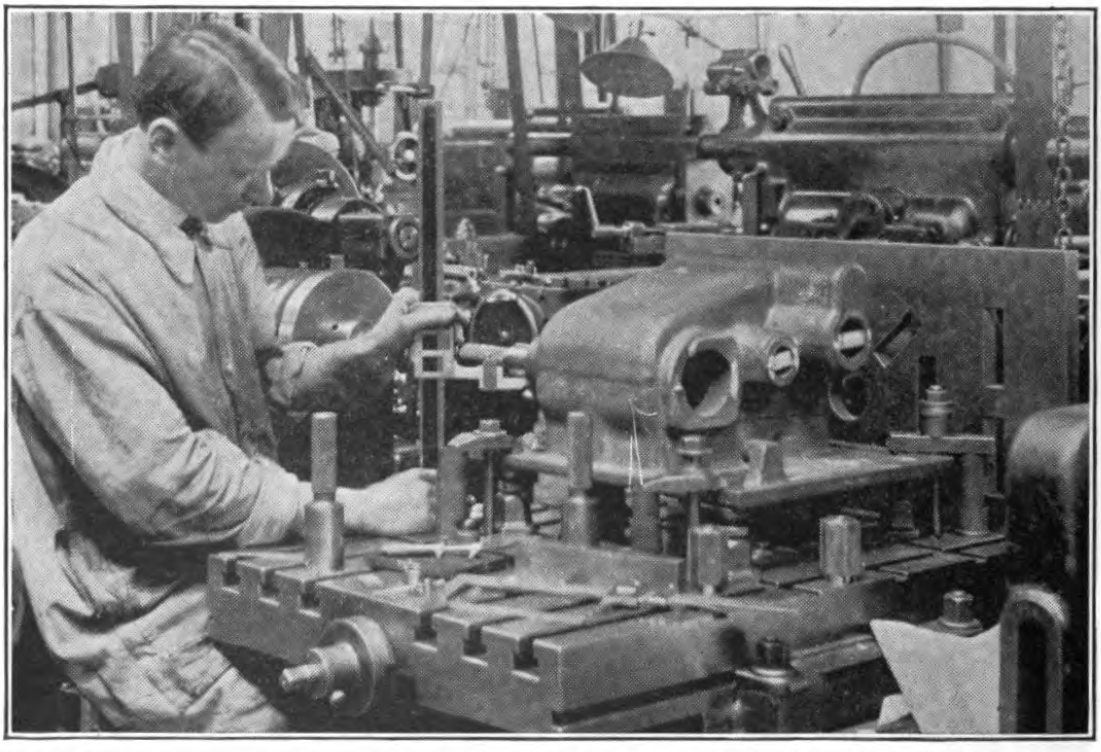


Fig. 236. A Toolmaker Measuring the Center Distance of a hole in a casting. Note how the work is located and supported and also the Precision Tools in use

Gage, Screw Pitch Gages, Thickness Gages, Center Gages, Wire Gages and various other gages adapted to any particular work upon which he might be employed. A Test Indicator, V Block and Clamps, Toolmakers' Vise, Toolmakers' Clamps and Toolmakers' Buttons are also some of the more common tools usually found in the toolmaker's kit. Their variance, of course, depends upon the class of work in which he may specialize. A good toolmaker gives his tools the best of care and he is constantly replacing them with new or improved tools.

Small Cutting Tools. — As a toolmaker may at any time be called upon to make a reamer, drill, die, forming tool or milling

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cutter, a thorough understanding of the use and design of these tools is of considerable aid so that he may produce a good practical tool. A knowledge of drills should include straight fluted and spiral drills, and twist drills, together with their most advantageous cutting angles and clearances. This likewise applies to the various kinds of reamers, and the toolmaker should understand the construction of the expanding and inserted blade reamers; the proper angles and clearances for the single or three and four lip roughing and finishing reamers, rose reamers, fluted chucking reamers and the various distinctions between machine and hand reamers. A knowledge of tapers is essential to properly

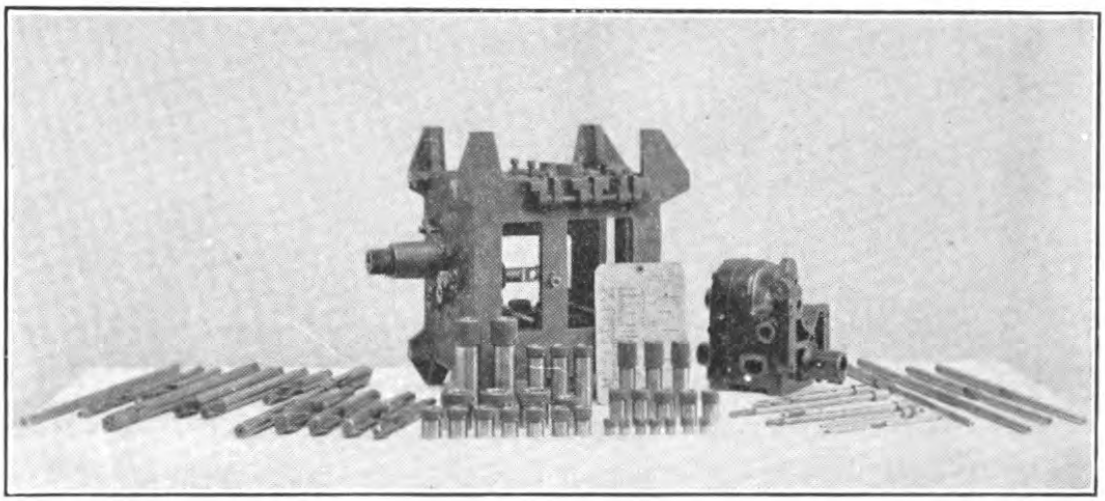


Fig. 237. A Typical Drill Jig and the Drills and Jig Bushings used in Locating and Drilling the holes in the piece shown on the right

make such tapered tools as taper reamers, taps, mandrels, and others. And what is true of these tools is likewise true of milling cutters, dies, counterbores, and numerous others of the small tools in everyday use in a machine shop.

Jigs and Fixtures. — Speaking in general, the distinction that exists between jigs and fixtures is that jigs are special devices for the purpose of guiding tools and of supporting work so that the work done on numerous pieces will be alike, independent of the skill of the operator; whereas, fixtures are devices

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that support and hold work with no particular reference to the guidance of the cutting tools. The toolmaker has ample opportunity to display his ingenuity in devising various arrangements for clamping or holding work in either jigs or fixtures and consequently possesses a knowledge of their various styles and forms, such as the box jig, slab jig and various others more complicated and used to hold intricate machine parts. See chapter under Welding for Jigs and Fixtures.

A good toolmaker must be familiar with the various methods of laying out and machining work. The accurate location and boring of holes by methods such as those requiring the use of plugs or toolmakers' buttons must be thoroughly understood in order to avoid waste of time in this important part of his work. One should possess a knowledge of the use of a Sine Bar and its application to various forms of work and be able to lay out and machine exacting angular work, such as dovetails, V slides and ways, and plane angular surfaces.

And lastly a good toolmaker is always a neat worker. He handles his drawings carefully; lays out his work painstakingly; and machines it accurately and carefully, keeping his machine clean and free from an unnecessary accumulation of chips and dirt. When lining up work or taking measurements he takes great care that all bearing surfaces are clean. The tools in his kit are kept in perfect condition and adjustment, for he realizes he is ever working " in thousandths " and consequently is dependent upon their accuracy.

A toolmaker is a master craftsman because he takes great pride in his work.

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CHAPTER XV

Materials of Construction

Cast Iron. — Its origin. — *Iron Ore.* — Three well known iron ores are: magnetite, 72.4% pure iron; hematite, 70%; and limonite, 60%. These ores come directly from the ground, from various parts of the world, and usually from open pit work-

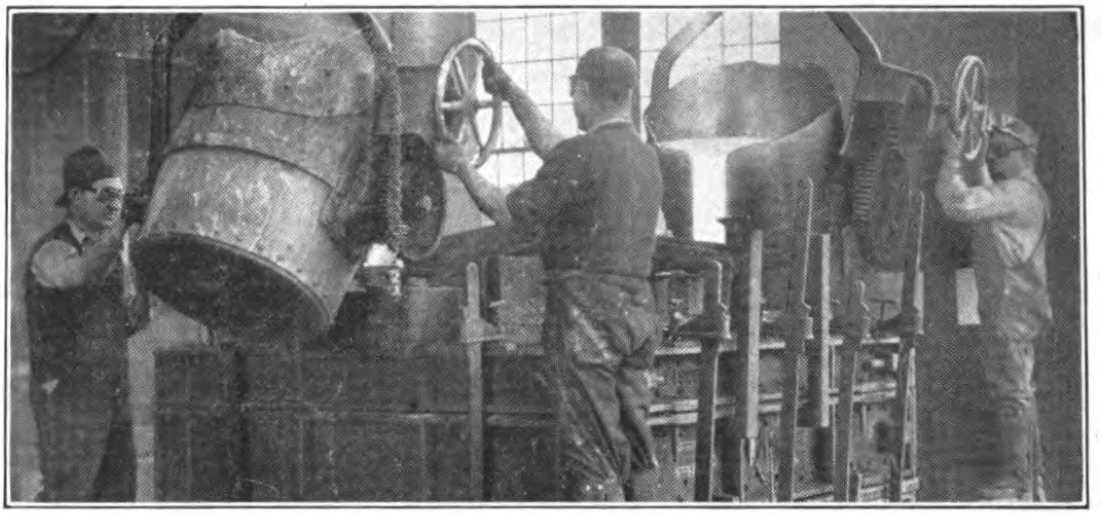


Fig. 238. Pouring a Large Casting in a Foundry

ings. *Pig Iron.* — Iron ore becomes pig iron by the removal of its mineral impurities in the blast furnace and the reduction of the ore to metallic iron by means of coke and the absorption of certain percentages of carbon, manganese, phosphorus, silicon and other substances.

Pig iron becomes cast iron in the cupola of the foundry. Cast iron contains varying percentages of carbon, silicon, sulphur, and phosphorus. It is usually made by remelting pig iron with coke as fuel and limestone as flux, together with old cast iron or steel scrap. It is neither malleable nor ductile. By quenching, it can be made as hard as tool steel and it can be chilled so that it becomes very hard. It can be readily molded into castings

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and it is particularly useful in construction where weight and mass are more essential than a high degree of strength. Vanadium added to cast iron makes it much stronger. The addition of nickel, copper, molybdenum or vanadium to cast iron produces varying qualities such as finer grain, greater hardness, wearing ability and resistance to shock. With the addition of varying percentages of chromium, white iron can be produced which has desirable wear resisting qualities.

High test cast iron which contains an additional percentage of steel is a very strong material compared to ordinary cast iron. With it, internal porosity can be eliminated where sections of a pattern are not entirely uniform.

Wrought Iron. — Wrought iron is one of the purest forms of iron and is made by removing the carbon and other impurities from pig iron. It is very resistant to progressive corrosion, and is soft, ductile and can be forged and welded readily. Under repeated stress, it is probably the weakest of all ferrous metals.

Because its physical properties are low and it is difficult to machine, wrought iron is used very little in machine tool manufacture, its principle uses being in the railroad, farm implement and oil industries.

Steel Castings. — Steel castings are made by melting steel, usually in electric or gas furnaces, and pouring the molten metal into molds which are similar to those used for iron castings. The casting of steel must be carefully controlled as otherwise considerable trouble may be experienced from blow holes. The castings, after being poured and allowed to cool, are usually given an annealing treatment to eliminate strains and to correct the structures of the steel.

The use of wood patterns to produce steel castings of desired shapes eliminates the making of dies which frequently are very costly.

Malleable Iron Castings. — Malleable cast iron castings are made from a special white iron. The castings are rendered malleable by a special annealing process which consists of heating

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the castings in annealing pots for several days at about 1375° F.

Malleable iron has fairly good physical characteristics and a good degree of ductility. It is used considerably in the machine tool industry for levers and similar machine parts. The automotive industry consumes over one half of the malleable iron produced, the material being used for such parts as brake and clutch pedals, differential carriers and rear axle housings. Its high ductility minimizes the hazard of sudden failure.

Drop Forgings. — Drop forgings are made from hot steel under a drop hammer in a variety of shapes depending upon the kind of die used. Most forgings require an annealing treatment after forging. This treatment relieves the strains of the hammering, gives refinement of structure to the steel and, also, puts it in a good condition for machining.

Brass. — Brass is generally an alloy of copper and zinc, although some brasses may contain other elements. Most commercial brass contains about 65% copper and 35% tin. Other alloys are frequently added so as to change its physical characteristics.

Free machining brass such as used in automatic screw machine work has about 62% copper, 35% zinc and 3% lead. Muntz metal, a brass containing 60% copper and 40% zinc, is used considerably for ship construction, particularly for sheathing, bolts and rivets exposed to the corrosive action of sea water.

Bronze. — Bronze is the general name for alloys of copper and tin. Frequently, other alloys such as zinc, lead, manganese, nickel, phosphorus and aluminum, are added to create desired characteristics. The standard worm wheel bronze contains about 88.5% copper, 11% tin, .25% lead and .25% phosphorus. A leaded bronze having 80% copper, 10% tin and 10% lead is an excellent bearing bronze and is used considerably in the machine tool industry. An aluminum bronze containing 89% copper, 10% aluminum and 1% iron is now being used considerably for spur, helical and bevel gears. This bronze may be heat treated to give increased physical properties. Manganese bronze having

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55% to 60% copper, 38% to 42% zinc, up to 3.5% manganese, up to 1.5% tin, up to 1.5% aluminum and 2% iron is probably the strongest of all bronzes. It is used for propellers, valve stems, lever arms, pump bodies and in many other mechanisms where strength is important.

Babbitt Metal is a very soft alloy, variable in its composition of tin, copper and antimony. It is used as lining for bearings and to reduce friction.

Steel. — Steel is a general term for iron with a lower carbon content than cast iron; cast iron may have 4% or more of carbon. For instance it has been recommended that 2.20% carbon be called the dividing line between cast iron and steel.

Machinery Steel is made from pig iron by reducing the carbon content and removing other impurities in a Bessemer converter or by the open-hearth process. Steel scrap of all kinds is used in the mixture. It contains from .25 to .50% carbon and can be easily forged and machined and is tough, ductile, malleable, and has a high compressive strength and shock resistance. Being low in cost, it is used in machine tools where resistance to shock is necessary but where no cutting edge or hardened surface is required.

Cold Rolled Machinery Steel has all the characteristics of soft machinery steel. It is made by passing ordinary soft machinery steel through highly finished rolls under great pressure. This gives it a very smooth finish and produces stock very close to size.

Carbon or Tool Steel contains approximately .5 to 1.5% carbon. It is produced by melting carbon and machinery steel or wrought iron in open hearth or an electric furnace. Carbon steel can be welded to machinery steel or wrought iron and, with greater difficulty, to carbon steel. It has a very high compressive and tensile strength and is tough, ductile, malleable but more brittle than machinery steel. It is more expensive and more difficult to work than cast iron, wrought iron, or ma-

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chinery steel. It is available in bars, disks, and sheets either annealed or unannealed. Tool steel may be readily hardened and it is used where cutting and compressive strength are required as for tools, drills, taps, dies, centers, mandrels, bearings and bushings.

Carbon in steel is represented in decimals to hundredths of a per cent; for instance, .25% carbon or "25 point carbon" indicates that by chemical analysis there are 25 hundredths of one per cent carbon in the steel. A test to distinguish carbon steel from machinery steel consists in heating it to a red heat and quenching in water. It is carbon steel, if it is "glass hard" to a fine file. If hardened to only a slight degree, it is probably machinery steel. When annealed, carbon steel can be machined with carbon steel tools. Sparks from a grinding wheel are a convenient way to distinguish different steels by comparing them with sparks of steel of a known analysis.

It might be of interest to note the following variations in the carbon content of steel in its relation to the uses of the steel: .15 to .25% constitutes cold rolled steel; .50 to .60% carbon in steel renders it most satisfactory for working while hot; .60 to .70% carbon is most suitable for tools when a sharpened edge is not required; .70 to .80% carbon for sets; .80 to 1.00% carbon for center punches, drills, knives, and chisels; 1.00 to 1.10% carbon for drills, punches, dies, and lathe tools; and 1.10 to 1.50% carbon for scrapers, lathe tools, reamers, and all tools requiring a particularly fine edge.

Drill Rod. — Drill rod is round, high grade, carbon steel drawn through accurate dies when cold in sizes from .013″ to approximately 1″. It is usually furnished in the cold drawn state, centerless ground, or centerless ground and polished. The tolerances to which drill rod is manufactured are very close.

Self-Hardening or Air-Hardening Steel. — Self-hardening or air-hardening steels are alloy steels that contain considerable alloying elements, such as tungsten, molybdenum, manganese and chromium, in addition to a normal amount of carbon. These

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steels, when brought to a hardening heat, harden by cooling in air.

High speed steel belongs to the air-hardening or self-hardening class. It consists of varying proportions of tungsten, molybdenum, chromium, cobalt, or vanadium. The 18-4-1 type (18% tungsten, 4% chromium, 1% vanadium) is the most widely used type at the present time.

High Speed Steel. — High speed steel, unlike carbon tool steel, has the property called red hardness which permits operation at high temperatures without appreciably softening. High speed steel of the analysis 18-4-1, just mentioned, will continue cutting until the edge of the tool reaches a temperature of approximately 1050° F. Carbon tool steel, when quenched, has about the same hardness as high speed steel, but when heat in excess of 350° F. is generated at the cutting edge, it becomes soft and will not cut.

A high speed steel containing between 7% to 10% molybdenum, together with chromium, tungsten and vanadium which has recently been introduced, is giving satisfactory results.

High speed steel hardens, when air cooled or oil quenched, from temperatures between 2200–2450° F. The 18-4-1 type usually hardens from 2375° F. It should be preheated to about 1550° F. and then placed in the high heat (2375° F.) furnace. To avoid scaling, it is usually quenched in oil. The drawing temperature varies but most high speed steel is drawn between 1000° F. and 1080° F. High speed steel may be annealed by heating to 1600° F. and allowing to cool in furnace. Sand and ashes are frequently used to avoid rapid cooling.

The red hardness characteristic of high speed steel permits higher surface speeds than carbon tool steel. It has replaced practically all carbon tool steel as a cutting tool.

Tungsten Carbide, better known as " Cemented Tungsten Carbide " is a dense and extremely hard material of almost diamond hardness containing a certain percentage of carbon, tungsten and cobalt. Its extreme hardness and resistance to abrasion make possible the cutting of certain hard materials.

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Cutters tipped with this material are not suited for exceptionally heavy cuts or feeds, but they permit the speed of the machine to be increased, thereby increasing the cutting speed. See also page 148.

For best results Tungsten Carbide edges should be well supported and rigid.

Stainless Steel. — Stainless steel is now used extensively in most all industries. It is a chromium-iron alloy, containing between 10% to 26% chromium. Nickel is often times added to insure better resistance to corrosion. The 18-8 type (18% chromium, 8% nickel) is widely used in soda fountains, steam cooking equipment, pasteurizing equipment, dye kettles and other similar implements.

The original stainless steel is of the cutlery type, having about .35% carbon and 13.5% chromium. This steel can be machined readily and can be hardened to about 500 Brinell hardness. To give best corrosion resistance, it should be used in the hardened condition.

The advent of the free machining stainless steel, by the addition of sulphur, zirconium sulphide, gives wider application to this alloy, particularly to the machine tool industry. The free machining stainless steels contain about .12% carbon, 12.00% to 15.00% chromium and .25% to .35% sulphur.

All stainless steels can be forged readily by heating to about 2100° F. It is good practice to anneal all forgings by heating to about 1350° F. to 1450° F. and allowing to cool in air or furnace. All the popular types of stainless steels can be welded except by the open fire method.

In pump rods, pump gears, precision tools, cutlery, dental tools, turbine blades, engine valves, oil burner parts, we find large applications of stainless steels.

Alloy Steels. — Alloy steels contain one or more alloying elements other than carbon in sufficient proportions to improve their physical properties and to make them more suitable for particular applications.

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Practically all alloy steels are manufactured by the open-hearth or electric furnace process. The most common alloying elements are nickel, chromium, vanadium and molybdenum.

The alloy steels are usually used in two carbon ranges: .15% to .25% carbon and .40% to .55% carbon. The former is the casehardening type, whereas the latter is the oil hardening or direct hardening type. Nickel molybdenum and chrome nickel steels are used extensively for automobile transmissions and milling machine gears.

Chrome bearing or ball bearing steels are those steels having about 1.00% carbon and 1.40% chromium. Ball bearings, roller bearings, spindle sleeves, practically all use chrome ball bearing steel. Most of the alloy steels, such as S.A.E. 3250, 3150, 6150, 5150 are oil quenching steels, the oil quenching reducing the tendency to crack in hardening. Chrome vanadium steel is used considerably for springs.

To identify the composition of the many alloy steels, a simple index system has been devised by the Society of Automotive Engineers (S.A.E). In this system, the first digit or letter of the descriptive number indicates the class to which the steel belongs. Digits commonly used appear in the following list with the steels for which each is used.

1. Carbon steels
T. High manganese steels
2. Nickel steels
3. Nickel chromium steels
4. Molybdenum steels
5. Chromium steels
6. Chromium vanadium steels
7. Tungsten steels
9. Silicon manganese steels

The prefix " X " is used in several instances to denote variation in the range of manganese, sulphur or chromium and frequently the prefix " T " is used for the high manganese steels.

The second digit of the number indicates the approximate

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percentage of the predominating alloy and the last two digits represent the carbon content in " points " or hundredths of one per cent.

Thus, 6150 belongs to chrome vanadium class (6) 1% chromium and has approximately .50% carbon.

Aluminum Alloy. — Aluminum alloy contains aluminum and copper, and is used extensively in the automotive and aeroplane industry as well as the machine tool industry. The lightness in weight of aluminum castings makes them very desirable where weight is an important factor. Aluminum also possesses good machining qualities. An alloy such as S.A.E. 38 can be heat treated to produce good mechanical properties. This alloy has the following composition:

Copper	4.0% — 5.0%
Silicon	Not over 1.20%
Iron	Not over 1.20%
Zinc	Not over .25%
Aluminum	Remainder

Such alloy is used for milling machine arbor yokes, windshield frames and aircraft crank cases. For automobile engine pistons, a silicon aluminum bronze (Silicon about 13%) is largely used. This alloy has a low coefficient of expansion and possesses good resistance to wear.

Free machining aluminum is now being used extensively for automatic screw machine work. An alloy having 5.5% copper, 5.5% lead, .5% Bismuth, with remainder aluminum, gives excellent machining qualities.

Caution in Regard to Cutting Steel from the Bar. — Always use a saw or a cutter when cutting a piece of tool steel. The practice of nicking with a chisel and then breaking with a sharp blow of the hammer is not recommended. The sudden fracture of the metal when in a cold state has the effect of upsetting the structure of the steel at the point of fracture and an inferior piece of stock is the result. If the steel is heated it may be cut with a chisel without damage.

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Changes in Material due to Various Causes. — A piece of work is almost sure to become sprung by cutting or drilling it, or by driving a key or a pin into it. A piece may be contracted and its holes may be made smaller by shrinking a ring around the outside.

A center that has been taken out of a spindle may not always be true when put back again. The face plate, although it may have been squared up and made true on a spindle, may not be true after being removed and replaced. A piece of work that has been turned on a mandrel and taken off may not run true when put on the mandrel again, and it is less likely to run true if placed on another mandrel. Likewise it is never certain when "breaking-up" a job on a planer that an angle plate or V blocks can be replaced "true," in relation to the work previously planed, after they have once been taken off. In bolting work against a plate, the plate and work often spring out of true, and if left in this condition will be inaccurately machined.

While external influences easily change nearly everything used in machine work, internal influences are also constantly effecting changes. A hardened steel bar which has been ground true may be sprung by a little heat; in fact a hardened bar is more likely to spring out than an unhardened one. It is thought that the tendency to spring may be reduced by annealing. It is frequently advisable to turn off a roughing chip all around, and then to clamp the work as lightly as practicable and turn off the finishing chip. Remember, therefore, that tendencies to change are always present in the materials you work with, and to do accurate work you must anticipate these changes as much as possible.

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CHAPTER XVI

Heat Treatment

In the course of his shop work the apprentice will soon hear steel referred to as being annealed, hardened, casehardened, and tempered; consequently he should become acquainted with those terms associated with the heat treatment of steel. Annealing steel is to make it soft, that it may be readily worked or machined. Hardening steel is to make it hard in order that it may better resist wear or be used for cutting tool purposes. Tempering consists of reheating the metal after hardening to some temperature below the hardening temperature so as to release hardening strains and to decrease the brittleness and increase the ductility or toughness.

Frequently, a hard surface is required on a gear or shaft in addition to good toughness. To obtain this hard surface, low carbon steels (not exceeding .25% carbon) are used and a process known as carburizing and casehardening is employed.

Annealing Steel. — This operation consists of heating the steel to the desired temperature, usually to a clear red, and allowing it to cool slowly. This is accomplished in the furnace, or if the steel is packed in charcoal, cast iron chips, or ashes it is allowed to cool in the pipes or boxes in which it is packed. The temperature used depends on the steel being annealed. A low carbon steel requires a higher heat than a high carbon steel. The temperature for annealing should be just below the critical range of the steel.

Casehardening Steel. — Steel to take a good casehardening should be fairly low in carbon. A percentage of .15 to .25 carbon is considered about average although some manufacturers use a wider range, going as high as .40% carbon. In such instances great care must be taken and the casehardener should know the steel that he is handling in order to get the best results.

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The parts to be casehardened are packed in pipes or boxes with bone and leather or charcoal or any good casehardening material. The pipes or boxes are then put in the furnace and given the correct temperature and time necessary to get the depth of case desired. If a case 1/32″ deep is wanted, the heat should be from 1600° F. to 1650° F. and held at this heat from 3 1/2 to 4

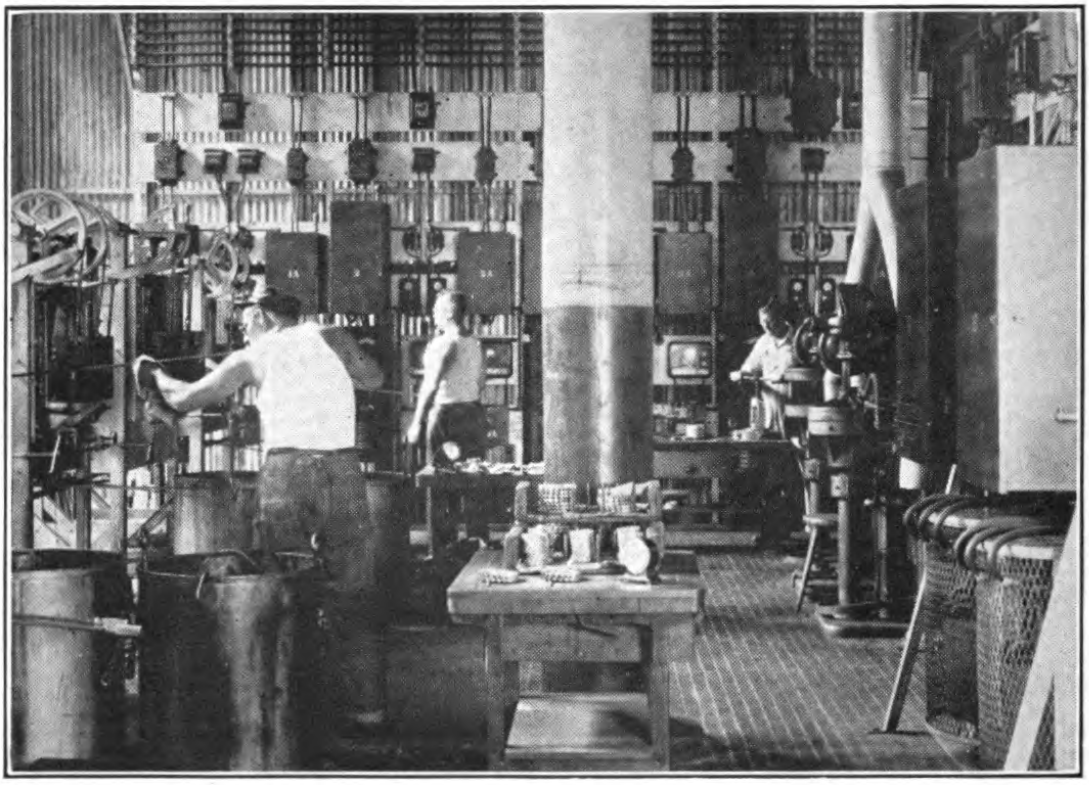


Fig. 239. View of a Hardening Room, showing furnaces for hardening High Speed Steel Cutters

hours after the pipes or boxes are heated through. The pipes or boxes should then be taken out and allowed to cool. They are then unpacked and given a heat treatment of from 1550° F. to 1600° F., then quenched in oil. This is done to refine the core. The parts are then heated to about 1420° F. and quenched in oil or brine depending on the size and shape. This treatment will refine and harden the case, leaving the core in good condition.

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When only a light case is necessary, say .010″ to .015″ deep, it is not necessary to use such a high carbonizing temperature. The parts are generally casehardened in one heat at approximately 1460° F. and quenched directly from the pipes or boxes into oil or brine, as desired.

When only a very light case is necessary .003″ or .004″ deep cyanide hardening is employed. This consists of heating the parts in a bath of cyanide, the temperature of the bath being held between 1400° F. and 1500° F. and the pieces kept in the cyanide long enough to absorb sufficient carbon to get the depth of casehardening desired. Parts are quenched in oil or brine when taken out of the cyanide.

Tool Steel Hardening. — Hardening tool steel parts like most hardening must be done carefully, using different methods and means of heating for the different kinds of work. For example, saws and screw slotting cutters are heated in a muffle furnace, laying them flat on the tile. They are quenched in oil or brine, thin ones in oil, and the thicker ones in brine. End mills, reamers, and bits are generally heated in lead, as it is necessary to harden only the cutting and tang ends, the rest being left soft. Milling cutters, side mills, gear cutters, can be heated in oil, gas or electric furnaces and hardened in brine and oil.

The heat used to harden tool steel is approximately 1400° F. to 1450° F. or just above the critical range. Sometimes on large pieces it is necessary to go slightly higher than 1450° F.

High Speed Steel Hardening. — In hardening high speed steel, electric, gas or oil furnaces are generally used. The hardener operates two furnaces, one called the preheat furnace, having a temperature of about 1500° F., and the other the high heat or hardening furnace, temperature of from 2300° F. to 2450° F., depending on the nature of the steel. The work to be hardened is placed in the preheating furnace and, when heated through, is then transferred to the high heat furnace and brought up quickly to the hardening heat. The work is then quenched in

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oil or cooled in an air blast. High speed steel is never quenched in water. Following quenching or cooling it is drawn to about 1050° F.

Tempering Steel. — It is sometimes necessary to temper certain parts after being hardened, for the purpose of restoring some of the ductility. This is done by reheating in an electric, gas or oil fired furnace, using an open furnace or a bath of oil in which to put the work. The temperature is noted on a thermometer or recorder and the heat very carefully controlled. The tempering heats used vary from 300° F. to 1100° F. and parts should be drawn just enough so that they will not be brittle or too soft. Most furnaces are now equipped with temperature recording instruments.

Tempering high speed steel is done at from 1050° F. to 1100° F.; tool steel from 300° F. to 450° F.; casehardened parts 300° F. to 475° F. These heats are all approximate and vary to suit individual cases. In some instances it is necessary to draw temper to color, but these instances are comparatively few.

The Color Test for Tempering Steel. — After brightening the surface of the piece to be tempered, heat gradually. As the piece increases in temperature a change of color will be observed on the bright surface. The colors will range from a pale yellow, through straw shades, purple, to gray or black, at which color it may be concluded that very little hardness remains. By reference to the Tempering Table, it will be possible to obtain an approximate degree of hardness by quenching the piece at the appearance of the proper color. The thermometer test is the only truly reliable method and it should always be used where a large number of pieces are to be tempered.

Small pieces may be tempered uniformly by immersing them in a box of sand which has been heated to the required temperature. When the pieces show the desired color they may be quenched in oil or water. Lathe tools and chisels are usually hardened in the open fire; reamers, taps, arbors, mandrels, and drills should be surrounded by the arch and sides of the furnace

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COLORS AND TEMPERATURES FOR TEMPERING STEEL

Color	Temp., Deg. (F.)	Kind of Tool
Very pale yellow	430	Light turning tools, scrapers, lancets.
Pale yellow	450	Surgical instruments, razors.
Medium yellow or light straw	460	Lathe tools, milling cutters.
Full yellow or straw	470	Drills for iron or steel, pen-knife blades.
Brown	490	Reamers, taps, dies for screw cutting, small cutlery, shears.
Brown, with purple spots	510	Axes, planes, knife blades, wood chisels.
Purple	530	Twist drills, cold chisels for very light work, table knives, large shears.
Dark blue	550	Wood saws.
Full blue	560	Stone-cutting chisels, fine saws, daggers.
Medium blue	580	Carving knives.
Light blue	600	Drills for wood, cold chisels, swords.

to protect the work from the air so that the fire will give a uniform heat.

A small gas heater is convenient for tempering small tools and other small parts.

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CHAPTER XVII

Welding

The process called welding is used on many kinds of metal and applied in different ways with several types of apparatus. It consists essentially of joining together two separate pieces of metal into one solid piece.

While the oldest type of welding, forge welding, is performed almost exclusively on iron and steel, brass, bronze, aluminum, lead, stainless steel, monel and other metals are satisfactorily welded with present day equipment.

Forge Welding. — There are several types of forge welds: scarf, lap, butt, cleft and jump welds, the names being descriptive of the general type of weld as shown in Fig. 240.

Scarf Weld. — This weld is made by first forming so called scarfs on the ends of the metal to be joined. A scarf is made by upsetting or thickening the material at the point where the welding is to be done and then hammering out the scarf on each piece. The scarfs are heated to the proper welding heat in the forge and the work quickly transferred to an anvil where the pieces are hammered together forming one solid piece. The centers of the scarfs should be crowned, as shown in the illustration, Fig. 240, so that when the two pieces are brought together at welding heat the high central points will meet first, squeezing the slag and impurities on the surface toward the outside as the pieces are hammered together. The surface of the metals to be welded are similarly prepared for lap, butt, cleft and jump welds.

The fuels used for forge welding are bituminus coal, coke, charcoal, fuel oil and gas. Of these, bituminus coal and coke are used most commonly. Clean fires and a controlled air blast are necessary, because if the heat is too low and the metal does not

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reach a plastic state it will not weld. On the other hand, if too much heat is used, the metal will be burned and ruined.

Fluxes are used as a further aid in making welds. These are supplied commercially or may be made in the shop. Fine clean

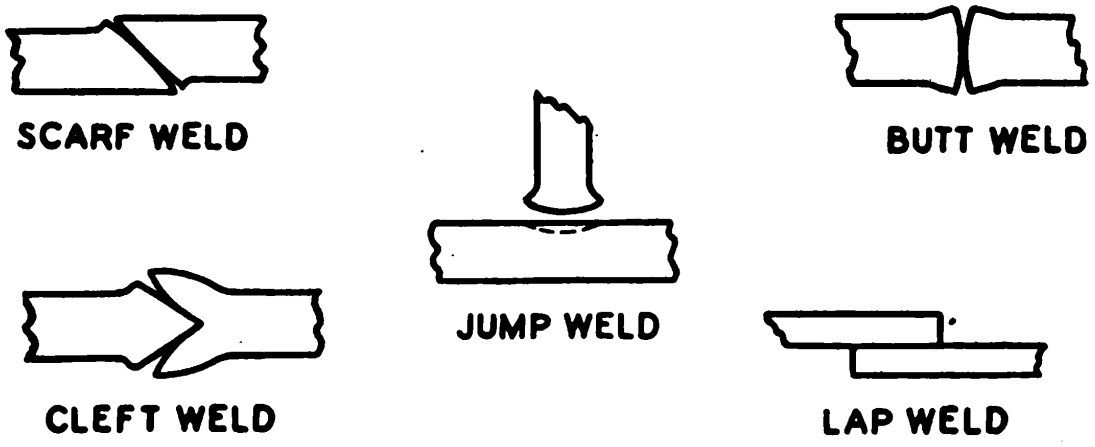


Fig. 240. Different Types of Forge Welds

sand is used for iron welding, while borax or a mixture of sand and borax is used for steel. Melting or fusing, and then cooling and pulverizing the borax improves its action as a flux.

The fluxes are applied by either dipping the work into the flux or applying it with a long-handled spoon. The action of the flux is to form a protective coating over the heated area, preventing oxidation and burning.

Autogenous Welding. — This type of welding differs from forge welding in that no hammering is needed to make the weld, and the heating is performed with an oxy-acetylene torch or blowpipe.

The torch or blowpipe is a piece of apparatus designed to regulate the mixture of the gases and deliver them to the tip end in the best form for combustion with the correct type of flame for the work to be welded.

Oxygen and acetylene are the gases usually used for this type of welding, and when correctly mixed and delivered at the tip of the torch, provide a temperature of about 6300° F. (approx.).

Oxygen is usually obtained commercially in metal pressure

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tanks or cylinders, holding up to 220 cubic feet at 2000 lbs. pressure per square inch.

Acetylene gas is sometimes made from carbide in an acetylene generator near the welding shop, or it can be obtained commercially in tanks or cylinders. The cylinders contain from 100 to 300 cubic feet of acetylene, these cylinders being specially prepared with a substance called acetone which has the property of absorbing an amount of acetylene several times its own weight. Both the oxygen and stored acetylene are kept in the cylinders at high pressure.

Pressure gages attached to a regulator are used to convert these high pressure gases to the lower pressure required by the welding torch and to maintain a steady flow of gas as used. This apparatus, called a regulator, is attached to a cylinder and indicates on one dial the high pressure in the cylinder and on another dial the lower pressure for the torch which is regulated by an adjusting device by the operator. The torch is equipped with valves for final regulation of the acetylene and oxygen.

It is extremely important that the welder should master a thorough and complete understanding of the handling of this apparatus before attempting its use, both from the standpoint of safety and economy. The valves on any cylinder or generator should never be opened until their proper handling is thoroughly understood.

Most autogenous welding on iron and steel is done with a neutral flame, A, Fig. 241, of oxygen and acetylene which is obtained by adjusting, by means of the valves on the torch, the flow of each of the gases from the tip, D, in such volume as to balance each other with the inner cone, C, as long as it can be made. This flame neither oxidizes nor carbonizes. On some types of non-ferrous metals a slightly oxidizing flame is desirable, Fig. 242, while on certain steel welding such as pipe welding and welding alloys, a carbonizing flame gives best results, Fig. 243.

Figure 243 shows results of varying the mixture of oxygen and acetylene. With an excess of acetylene a luminous feather,

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B, extends beyond the inner cone, C. With an excess of oxygen in the mixture, Fig. 242, the inner cone is shorter and does not have this luminous feather, while with a neutral welding flame having proper mixture of gases the longest possible cone is obtained.

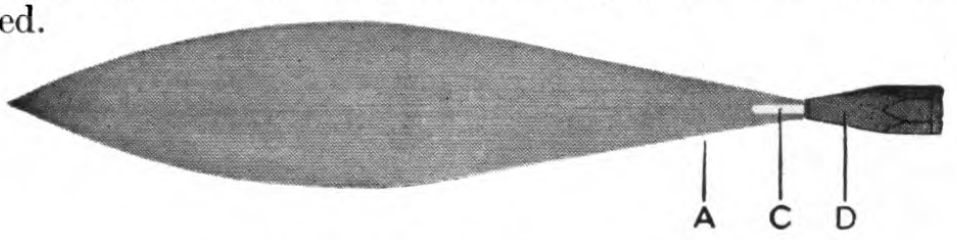


Fig. 241. A Neutral Flame

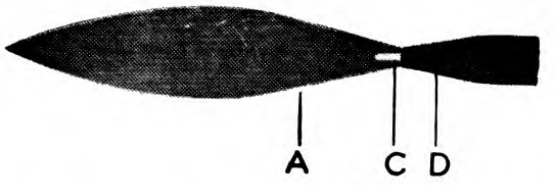


Fig. 242. An Oxidizing Flame — An Excess of Oxygen Present

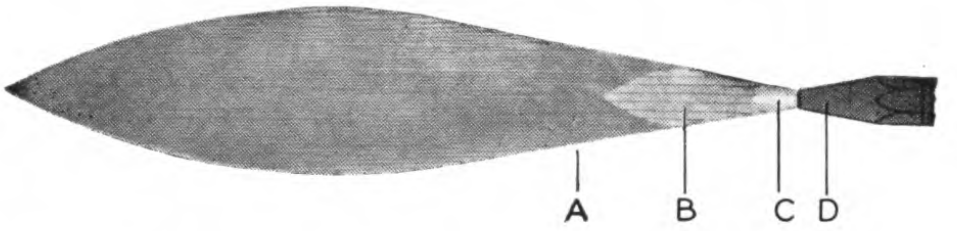


Fig. 243. A Carbonizing Flame — An Excess of Acetylene Present

The color of the inner cone is of a bluish white and the welding flame is of a purple hue, this shade depending upon the purity of the gas used. The color and shape of the flame indicate to an experienced welder the mixture of oxygen and acetylene to use for various types of welding.

Tips with openings of different diameters are provided with each torch to provide for the requirements of different thicknesses of metal.

In addition for welding there are many kinds of filler metals in rod form available for adding metal in welds when it is necessary.

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Many different kinds and grades of metals can be successfully welded by this process; a few are iron, steel, cast iron, brass, bronze, aluminum, lead, stainless steel and monel metal.

Electric Welding. — This type of welding uses the heat made by an electric arc between a positive and negative terminal in the electric circuit. The part to be welded is, due to its greater mass, connected by suitable cable leads to either the positive or negative side of the electric circuit, while the electrode is connected to the opposite side. The electrode may be a metal wire or a carbon rod. Most work is done by metallic arc welding. When the carbon rod is used, the process is called carbon arc welding.

When an arc is drawn between a metallic electrode and the work, both the work and the electrode are melted and flow together forming a homogeneous mass. When the carbon electrode is used, only the work piece is melted and if metal is to be added, a filler rod of the desired metal is held in the arc and melted into the weld.

The welding current may be taken through apparatus designed to convert the available current supply to current suitable for welding and this type of welding is called alternating current welding, or it may be supplied by a direct current generator designed especially to supply welding current. There are many types and sizes of arc welding equipment, some of which are especially adapted to certain and specialized classes of welding. Other types are more universal and lend themselves to general requirements.

Metallic electrodes are almost unlimited as to kind and size, ranging from bare wire to very heavy coated wire. The wire, coating, or both are made to supply or replace elements burned away by the high heat of the arc or to deposit an entirely different kind of metal on the work. In hard surfacing, for example, an electrode made up of a substance which may or may not be steel, when melted in the arc and deposited on the work, resists wear and abrasion much longer than the parent metal.

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Welding with coated electrodes gives a better deposit of higher strength and density than with uncoated wires, due to the protection afforded by the coating.

The length of the arc, that is the distance the electrode is held from the work while welding, is very important. A long arc allows contamination to enter the weld, making a porous, open grained structure with low strength. A short arc tends to prevent this by excluding the air to a greater extent and depositing the metal in a more concentrated area.

Arc welding is applied generally to ferrous metals, although some arc welding is done quite successfully on non-ferrous metals.

Resistance Welding. — Resistance welding is accomplished by holding two pieces of work in contact with each other and passing an electric current through them. As the points of contact offer the greatest resistance to the current, they will heat more quickly than the main bodies of the metals. When welding temperature is reached, pressure is applied mechanically to force the parts together completing the weld.

The types of resistance welding are Butt, Flash, Spot and Seam welding.

Butt Welding. — Butt welding consists of clamping the two pieces in suitable holders forcing them together end to end and applying the current allowing the resistance at the point of contact to cause heating. When the two pieces become sufficiently hot at the juncture additional pressure is applied forcing the metal to unite as one piece with approximately 85% of the original metal.

Flash Welding. — Flash welding has almost completely taken the place of butt welding and consists of supplying a much higher secondary voltage which is turned on before the two parts to be welded are in contact. When the two pieces approach each other closely this causes an electric arc to occur. As the electric arc has the highest known temperature the pieces are quickly heated to the welding temperature when, by suitable equipment, tre-

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mendous pressure is applied to force the parts together to complete the weld.

Spot Welding. — Spot welding, another branch of resistance welding, is used principally to replace riveting. It consists of discharging a large volume of current at low voltage through two or more sheets of metal held under pressure between two electrodes. The amount of current, the time and pressure being variable by suitable controls, various thicknesses of metal can be welded. The electrodes are usually copper or an alloy of copper and other elements designed to make the electrodes wear longer. Special devices are used to automatically control the time the current is allowed to flow so that just the correct amount of heat to make the weld is supplied and each weld is correctly made.

Seam Welding. — Seam welding, still another branch of resistance welding, consists of passing two or more sheets of metal between two copper rollers. The electric current passing from roller to roller through the sheets heats them to the welding temperature and the pressure between the rollers completes the weld.

Special timing devices are also used to control the current and speed the same as for spot welding.

Metals weld best when in a plastic state that is between solid and molten and the metals which remain molten longest are thus easiest to weld and vice versa.

Protection in Welding. — Specially designed shields and helmets must be worn by the operator to protect his eyes (see Fig. 244) from the glare of the arc. Fireproof clothing should also be worn as a protection from the glare on the skin and from sparks.

The successful use of arc welding equipment requires considerable experience and should be attempted only after competent instruction, followed by considerable practice under proper supervision.

Atomic Hydrogen Welding. — In this form of welding an alternating current arc is maintained between two tungsten

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Fig. 244. Welder with Protective Equipment

electrodes in a stream of hydrogen supplied through the electrode holder. The heat of the arc breaks up the hydrogen into atoms which recombine outside the arc causing intense heat. This heat is used to complete the weld. The temperature of the arc is 6400° F. (approx.). The hydrogen, in addition to providing the means for intense heat, also acts to shield the weld metal, protecting it from the air, with resultant clean sound welds. This type of welding can be used for ferrous and many types of non-ferrous metals and is particularly suitable for welding thin sheet iron, steel, or brass metals.

The same precautions as for arc welding should be taken to protect the welder from injurious light rays and hot metal, and suitable protection is also necessary to prevent injury to other workmen nearby.

Welded Jigs and Fixtures. — Arc welding is today used successfully for the manufacture of jigs and fixtures (see Figs. 245, 246, 247, 248, 249 and 250) and some machine parts, and eliminates much special machine work with resulting economy. Expensive patterns which are required when such parts are made of cast iron are not necessary when welding is used. The

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tools are so designed as to permit the use of standard structural steel shapes with small surfaces to be machined. Parts are

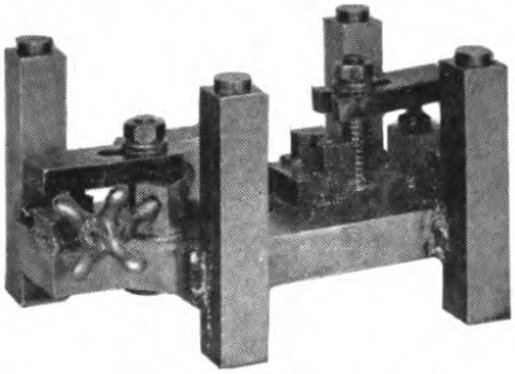


Fig. 245. This jig, with plate and posts arc welded, has a simple type of construction

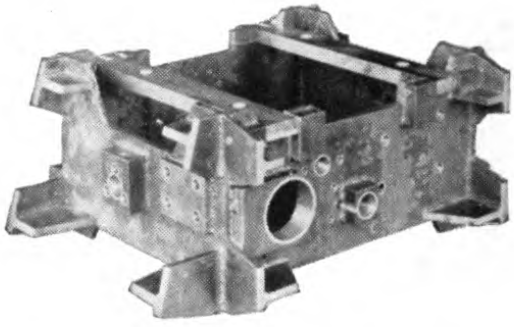


Fig. 246. Welded plates and angle irons are both used in the construction shown

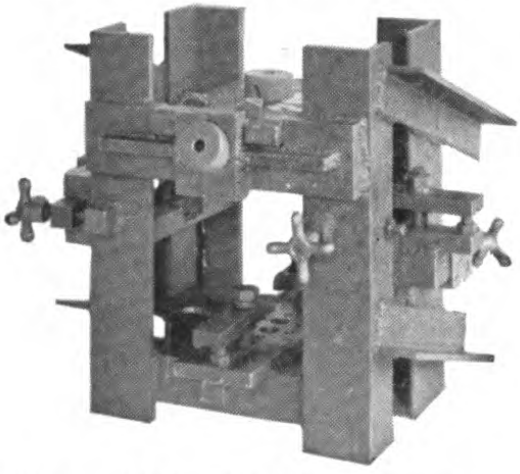


Fig. 247. Angle irons form the fundamental construction of this otherwise expensive jig

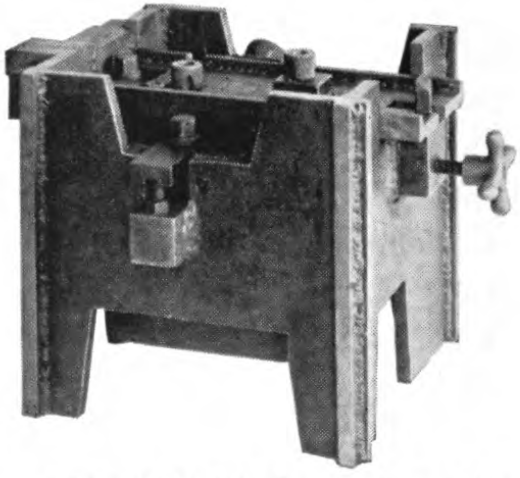


Fig. 248. Plates welded together reduce the cost of this jig and eliminate necessity of patterns

shaped and cut to size with the cutting torch and squared up, located, clamped in position and then tack welded to temporarily hold parts in their proper place.

When sufficiently assembled the parts are finished by arc welding. A substantial weld is necessary in proportion to the requirements of the work. The completed weld is normalized

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by heating to around 1300° F. and then allowed to cool to relieve any strains set up by the welding.

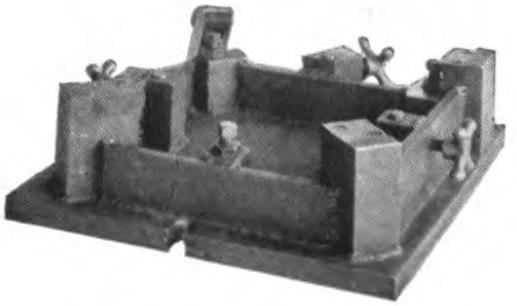


Fig. 249. Milling fixture made by welding

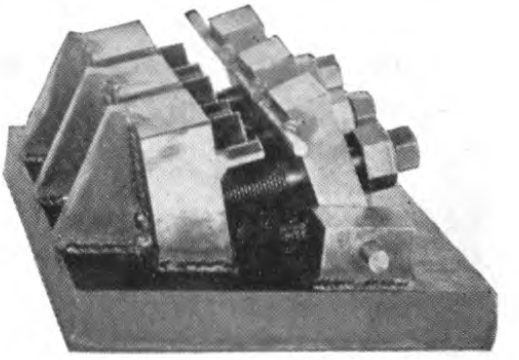


Fig. 250. Welded fixture for milling drill points

This method of manufacture has unlimited possibilities and the designer can exercise his ingenuity in bringing about almost any conceivable jig or fixture of light construction and required strength. This method is also used in fabricating many types of gages or testing devices. Also, surfaces which have excessive wear can be readily hard faced, using the welding processes.

In some cases the parts may be a little more difficult to machine than cast iron, but steel blocks of small size have correspondingly small areas to finish, eliminating the machining of large surfaces.

Gas Cutting. — Related to oxy-acetylene welding is the cutting of ferrous metals with torches, using oxygen with some other heating gas, such as acetylene or illuminating gas. The process of cutting is a chemical action, the same as the combustion of wood or other combustible material. To start the combustion of steel it is necessary only to heat a small area to a red heat and, by suitable means, to supply enough oxygen to continue the cutting process. A cutting torch is so constructed that it supplies the necessary heating flame and the extra oxygen necessary to continue the combustion of cutting. As the oxygen and gas are supplied through a specially designed nozzle, the cutting can be confined to a narrow space with the width of the

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kerf, or cut, being regulated by the thickness of the metal. As thicker metals require more oxygen for cutting, a larger nozzle is necessary and a wider kerf is made. Straight or irregular cuts can be made in steel with little finishing necessary to complete the work. Cast iron does not gas cut as well as steel and the kerf is

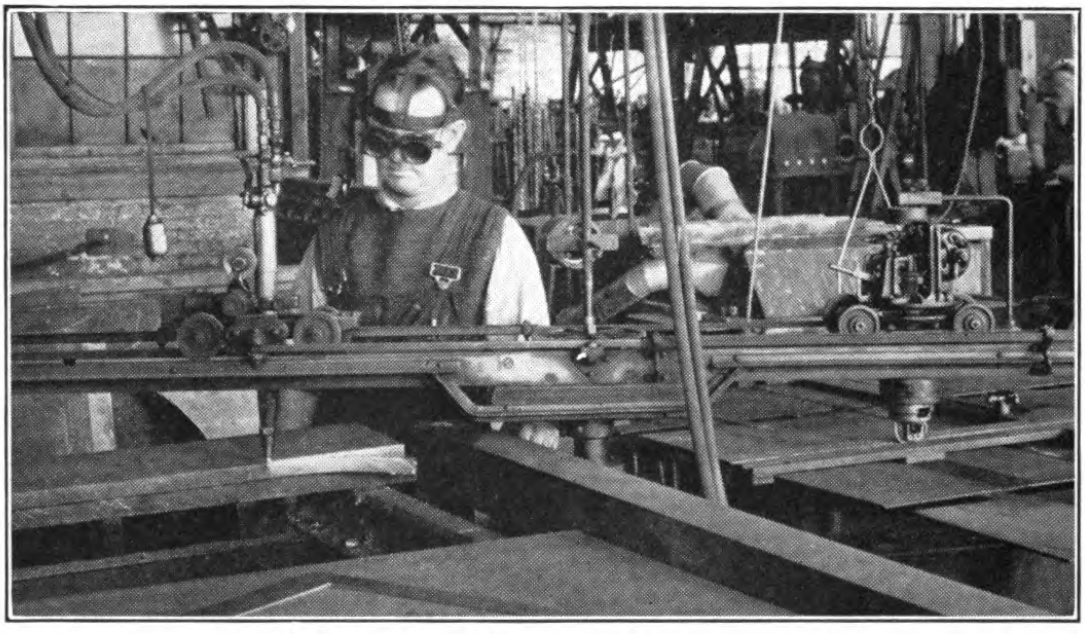


Fig. 251. Gas Cutting Machine in Use

wider. Also, the surfaces of cuts in cast iron are rough and may be too hard for machining unless annealed after cutting.

In addition to flame or gas cutting by hand there are machines, Fig. 251, which control flame cutting torches that cut practically any shape and thickness desired to very close tolerances. Much work is used as cut, no finishing being necessary on the cut surface. These machines can be used for welding by simply changing the torches from cutting to the welding type. Templates are used to control the direction of movement of the torch.

Flame Machining. — Turning and planing with the gas torch is done quite successfully. Torches of special design are held at such an angle to the work as to cut or burn away sufficient metal to leave only enough for finishing by regular machining methods. The power necessary need be only enough to move the work and the moving parts of the machine.

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TABLES

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DECIMAL EQUIVALENTS OF FRACTIONAL PARTS OF AN INCH

1/64 .01563	21/64 .32813	45/64 .70313
1/32 .03125	11/32 .34375	23/32 .71875
3/64 .04688	23/64 .35938	47/64 .73438
1/16 .0625	3/8 .375	3/4 .75
5/64 .07813	25/64 .39063	49/64 .76563
3/32 .09375	13/32 .40625	25/32 .78125
7/64 .10938	27/64 .42188	51/64 .79688
1/8 .125	7/16 .4375	13/16 .8125
9/64 .14063	29/64 .45313	53/64 .82813
5/32 .15625	15/32 .46875	27/32 .84375
11/64 .17188	31/64 .48438	55/64 .85938
3/16 .1875	1/2 .5	7/8 .875
13/64 .20313	33/64 .51563	57/64 .89063
7/32 .21875	17/32 .53125	29/32 .90625
15/64 .23438	35/64 .54688	59/64 .92188
1/4 .25	9/16 .5625	15/16 .9375
17/64 .26563	37/64 .57813	61/64 .95313
9/32 .28125	19/32 .59375	31/32 .96875
19/64 .29688	39/64 .60938	63/64 .98438
5/16 .3125	5/8 .625	1 1.00000
	41/64 .64063	
	21/32 .65625	
	43/64 .67188	
	11/16 .6875	

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MILLIMETER EQUIVALENTS OF FRACTIONAL PARTS OF AN INCH

Inches	mm	Inches	mm	Inches	mm
1/64	.397	21/64	8.334	45/64	17.859
1/32	.794	11/32	8.731	23/32	18.256
3/64	1.191	23/64	9.128	47/64	18.653
1/16	1.587	3/8	9.525	3/4	19.050
5/64	1.984	25/64	9.922	49/64	19.447
3/32	2.381	13/32	10.319	25/32	19.844
7/64	2.778	27/64	10.716	51/64	20.240
1/8	3.175	7/16	11.113	13/16	20.637
9/64	3.572	29/64	11.509	53/64	21.034
5/32	3.969	15/32	11.906	27/32	21.431
11/64	4.366	31/64	12.303	55/64	21.828
3/16	4.762	1/2	12.700	7/8	22.225
13/64	5.159	33/64	13.097	57/64	22.622
7/32	5.556	17/32	13.494	29/32	23.019
15/64	5.953	35/64	13.890	59/64	23.415
1/4	6.350	9/16	14.287	15/16	23.812
17/64	6.747	37/64	14.684	61/64	24.209
9/32	7.144	9/32	15.081	31/32	24.606
19/64	7.541	39/64	15.478	63/64	25.003
5/16	7.937	5/8	15.875	1	25.400
		41/64	16.272		
		21/32	16.669		
		43/64	17.065		
		11/16	17.462		

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DECIMAL EQUIVALENTS, SQUARES, SQUARE ROOTS, CUBES AND CUBE ROOTS OF FRACTIONS; CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1/64 TO 1 INCH

Fraction	Dec. Equiv.	Square	Square Root	Cube	Cube Root	Circum. Circle	Area Circle
1/64	.015625	.000244	.1250	.000003815	.2500	.04909	.000192
1/32	.03125	.0009765	.1768	.00003052	.3150	.09818	.000767
3/64	.046875	.002197	.2165	.000103	.3606	.1473	.001726
1/16	.0625	.003906	.2500	.0002442	.3968	.1973	.003068
5/64	.078125	.006104	.2795	.0004768	.4275	.2455	.004794
3/32	.09375	.008789	.3062	.0008240	.4543	.2945	.006903
7/64	.109375	.01196	.3307	.001308	.4782	.3436	.009396
1/8	.1250	.01563	.3535	.001953	.5000	.3927	.01228
9/64	.140625	.01978	.3750	.002781	.5200	.4438	.01553
5/32	.15625	.02441	.3953	.003815	.5386	.4909	.01916
11/64	.171875	.02954	.4161	.005078	.5560	.5400	.02321
3/16	.1875	.03516	.4330	.006592	.5724	.5890	.02761
13/64	.203125	.04126	.4507	.008381	.5878	.6381	.03241
7/32	.21875	.04786	.4677	.01047	.6025	.6872	.03758
15/64	.234375	.05493	.4841	.01287	.6166	.7363	.04314
1/4	.2500	.0625	.5000	.01562	.6300	.7854	.04909
17/64	.265625	.07056	.5154	.01874	.6428	.8345	.05541
9/32	.28125	.07910	.5303	.02225	.6552	.8836	.06213
19/64	.296875	.08813	.5449	.02616	.6671	.9327	.06922
5/16	.3125	.09766	.5590	.03052	.6786	.9817	.07670
21/64	.328125	.1077	.5728	.03533	.6897	1.031	.08456
11/32	.34375	.1182	.5863	.04062	.7005	1.080	.09281
23/64	.359375	.12913	.5995	.04641	.7110	1.129	.1014
3/8	.3750	.1406	.6124	.05273	.7211	1.178	.1104
25/64	.390625	.1526	.6250	.05960	.7310	1.227	.1226
13/32	.40625	.1650	.6374	.06705	.7406	1.276	.1296
27/64	.421875	.17800	.6495	.07508	.7500	1.325	.1398
7/16	.4375	.1914	.6614	.08374	.7592	1.374	.1503
29/64	.453125	.2053	.6732	.09304	.7681	1.424	.1613
15/32	.46875	.2197	.6847	.1030	.7768	1.473	.1726

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DECIMAL EQUIVALENTS, ETC. (*Continued*)

Fraction	Dec. Equiv.	Square	Square Root	Cube	Cube Root	Circum. Circle	Area Circle
31/64	.484375	.2346	.6960	.1136	.7853	1.522	.1843
1/2	.5000	.2500	.7071	.1250	.7937	1.571	.1963
33/64	.515625	.2659	.7181	.1371	.8019	1.620	.2088
17/32	.53125	.2822	.7289	.1499	.8099	1.669	.2217
35/64	.546875	.2991	.7395	.1636	.8178	1.718	.2349
9/16	.5625	.3164	.7500	.1780	.8255	1.767	.2485
37/64	.578125	.3312	.7603	.1932	.8331	1.816	.2625
19/32	.59375	.3525	.7706	.2093	.8405	1.865	.2769
39/64	.609375	.3713	.7806	.2263	.8478	1.914	.2916
5/8	.6250	.3906	.7906	.2441	.8550	1.963	.3068
41/64	.640625	.4104	.8004	.2629	.8621	2.013	.3223
21/32	.65625	.4307	.8101	.2826	.8690	2.062	.3382
43/64	.671875	.4514	.8197	.3033	.8758	2.111	.3545
11/16	.6875	.4727	.8292	.3250	.8826	2.160	.3712
45/64	.703125	.4944	.8385	.3476	.8892	2.209	.3883
23/32	.71875	.5166	.8478	.3713	.8958	2.258	.4057
47/64	.734375	.5393	.8569	.3961	.9022	2.307	.4236
3/4	.7500	.5625	.8660	.4219	.9086	2.356	.4418
49/64	.765625	.5862	.8750	.4488	.9148	2.405	.4604
25/32	.78125	.6104	.8839	.4768	.9210	2.454	.4794
51/64	.796875	.6350	.8927	.5060	.9271	2.503	.4987
13/16	.8125	.6602	.9014	.5364	.9331	2.553	.5185
53/64	.828125	.6858	.9100	.5679	.9391	2.602	.5386
27/32	.84375	.7119	.9186	.6007	.9449	2.651	.5592
55/64	.859375	.7385	.9270	.6347	.9507	2.700	.5801
7/8	.8750	.7656	.9354	.6699	.9565	2.749	.6013
57/64	.890625	.7932	.9437	.7064	.9621	2.798	.6230
29/32	.90625	.8213	.9520	.7443	.9677	2.847	.6450
59/64	.921875	.8499	.9601	.7835	.9732	2.896	.6675
15/16	.9375	.8789	.9682	.8240	.9787	2.945	.6903
61/64	.953125	.9084	.9763	.8659	.9841	2.994	.7135
31/32	.96875	.9385	.9843	.9091	.9895	3.043	.7371
63/64	.984375	.9690	.9922	.9539	.9948	3.093	.7610
1	1	1	1	1	1	3.1416	.7854

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DECIMAL EQUIVALENTS OF MILLIMETERS AND FRACTIONS OF MILLIMETERS

mm	Inches	mm	Inches	mm	Inches	mm	Inches
1-100 =	.00039	33-100 =	.01299	64-100 =	.02520	95-100 =	.03740
2-100 =	.00079	34-100 =	.01339	65-100 =	.02559	96-100 =	.03780
3-100 =	.00118	35-100 =	.01378	66-100 =	.02598	97-100 =	.03819
4-100 =	.00157	36-100 =	.01417	67-100 =	.02638	98-100 =	.03858
5-100 =	.00197	37-100 =	.01457	68-100 =	.02677	99-100 =	.03898
6-100 =	.00236	38-100 =	.01496	69-100 =	.02717	1 =	.03937
7-100 =	.00276	39-100 =	.01535	70-100 =	.02756	2 =	.07874
8-100 =	.00315	40-100 =	.01575	71-100 =	.02795	3 =	.11811
9-100 =	.00354	41-100 =	.01614	72-100 =	.02835	4 =	.15748
10-100 =	.00394	42-100 =	.01654	73-100 =	.02874	5 =	.19685
11-100 =	.00433	43-100 =	.01693	74-100 =	.02913	6 =	.23622
12-100 =	.00472	44-100 =	.01732	75-100 =	.02953	7 =	.27559
13-100 =	.00512	45-100 =	.01772	76-100 =	.02992	8 =	.31496
14-100 =	.00551	46-100 =	.01811	77-100 =	.03032	9 =	.35433
15-100 =	.00591	47-100 =	.01850	78-100 =	.03071	10 =	.39370
16-100 =	.00630	48-100 =	.01890	79-100 =	.03110	11 =	.43307
17-100 =	.00669	49-100 =	.01929	80-100 =	.03150	12 =	.47244
18-100 =	.00709	50-100 =	.01969	81-100 =	.03189	13 =	.51181
19-100 =	.00748	51-100 =	.02008	82-100 =	.03228	14 =	.55118
20-100 =	.00787	52-100 =	.02047	83-100 =	.03268	15 =	.59055
21-100 =	.00827	53-100 =	.02087	84-100 =	.03307	16 =	.62992
22-100 =	.00866	54-100 =	.02126	85-100 =	.03346	17 =	.66929
23-100 =	.00906	55-100 =	.02165	86-100 =	.03386	18 =	.70866
24-100 =	.00945	56-100 =	.02205	87-100 =	.03425	19 =	.74803
25-100 =	.00984	57-100 =	.02244	88-100 =	.03465	20 =	.78740
26-100 =	.01024	58-100 =	.02283	89-100 =	.03504	21 =	.82677
27-100 =	.01063	59-100 =	.02323	90-100 =	.03543	22 =	.86614
28-100 =	.01102	60-100 =	.02362	91-100 =	.03583	23 =	.90551
29-100 =	.01142	61-100 =	.02402	92-100 =	.03622	24 =	.94488
30-100 =	.01181	62-100 =	.02441	93-100 =	.03661	25 =	.98425
31-100 =	.01220	63-100 =	.02480	94-100 =	.03701	26 =	1.02362
32-100 =	.01260	.....		.....		.....	

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ALLOWANCES FOR FITS

The allowances given in the table are recommended for use in the manufacture of machine parts, to produce satisfactory commercial work. For special cases, it may be necessary to increase or decrease the allowances given in the table.

Running Fits for Shafts — Speeds Under 600 R.P.M. — Ordinary Working Conditions

Diameter, Inches	*Allowances, Inches*
Up to ½	−0.0005 to −0.001
½ to 1	−0.00075 to −0.0015
1 to 2	−0.0015 to −0.0025
2 to 3½	−0.002 to −0.003
3½ to 6	−0.0025 to −0.004

Running Fits for Shafts — Speeds Over 600 R.P.M. — Heavy Pressure — Working Conditions Severe

Up to ½	−0.0005 to −0.001
½ to 1	−0.001 to −0.002
1 to 2	−0.002 to −0.003
2 to 3½	−0.003 to −0.004
3½ to 6	−0.004 to −0.005

Sliding Fits for Shafts with Gears, Clutches, or Similar Parts which must be Free to Slide

Up to ½	−0.0005 to −0.001
½ to 1	−0.00075 to −0.0015
1 to 2	−0.0015 to −0.0025
2 to 3½	−0.002 to −0.003
3½ to 6	−0.0025 to −0.004

Standard Fits for Light Service where Part is Keyed to Shaft and Clamped Endwise — No Fitting

Up to ½	Standard to −0.00025
½ to 3½	Standard to −0.0005
3½ to 6	Standard to −0.00075

Standard Fits with Play Eliminated — Parts Should Assemble Readily — Some Fitting and Selecting may be Required

Up to ½	Standard to +0.00025
½ to 3½	Standard to +0.0005
3½ to 6	Standard to +0.00075

Driving Fits for Permanent Assembly of Parts so Located that Driving cannot be done readily

Up to ½	Standard to +0.00025
½ to 1	+0.00025 to +0.0005
1 to 2	+0.0005 to +0.00075
2 to 6	+0.0005 to +0.001

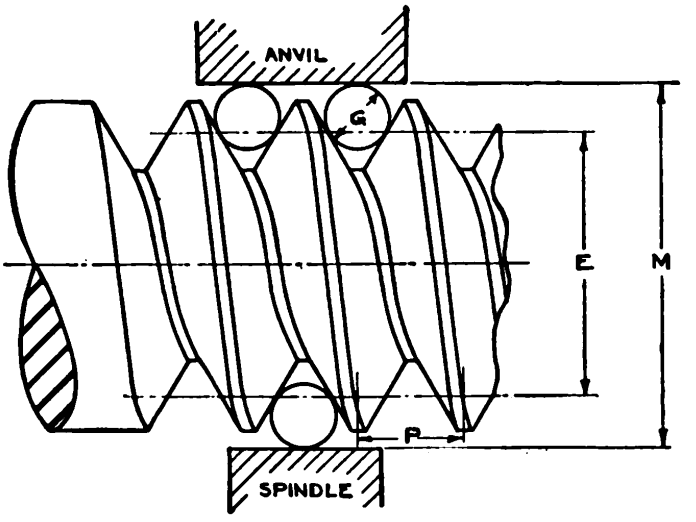
Driving Fits for Permanent Assembly and Severe Duty and where there is Ample Room for Driving

Up to 2	+0.0005 to +0.001
2 to 3½	+0.00075 to +0.00125
3½ to 6	+0.001 to +0.0015

Forced Fits for Permanent Assembly and Very Severe Service — Hydraulic Press Used for Larger Parts

Up to ½	+0.00075 to +0.001
½ to 1	+0.001 to +0.002
1 to 2	+0.002 to +0.003
2 to 3½	+0.003 to +0.004
3½ to 6	+0.004 to +0.005

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THREE WIRE METHOD FOR MEASURING PITCH DIAMETERS

Wire Sizes and Formulae for 60° Threads

To find the Pitch Diameter (E)

(1) $E = M + 0.866025\ P - 3G$

To Calculate the Measurement over Wires (M)

(2) $M = E + 3G - 0.866025\ P$

E = Pitch Diameter P = Pitch

M = Measurement over Wires G = Diameter of Wires

Example: — Determine (M) Measurement over Wires for ½"— 12 Pitch N. C.

Nominal Major Diameter	.500000"
Less Single Depth of 12 P. Natl. Std.	.054126"
Pitch Diameter is	.445874"

Size of Wire to use on 12 P is .0481125" (See Table)

Using Formula (2)

$M = .445874'' + (3 \times .0481125'') - 0.866025\ P$

$M = .445874'' + .144337'' - .072168''$

$M = .445874'' + .072169''$

$M = .518043''$

By using different formulae, threads of other proportions can be accurately measured.

A wire that comes in contact with the side of the thread at the pitch line is called the " Best Size." Larger wires can be used, but the " Best Size " gives the reading at the important working part of the thread. (Smaller sizes come below the top of the thread.) The " Best Size " of wire for each pitch is given in the following table.

Too much pressure should not be applied when measuring over wires. For pitches finer than 20 threads per inch a pressure of 1 pound is recommended and 2½ pounds for pitches of 20 threads per inch and coarser.

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WIRE SIZES

For Three Wire Thread Measurement of American National Form Threads

Wire Sizes	Threads Per Inch								
	3	3¼	3½	4	4½	5	5½	6	7
.192450	*.28867	.31088	.32992						
.177646	.....	*.26647	.28551	.31643					
.164957	.....	.....	*.24744	.27837	.30242				
.144339	.....	.....	.....	*.21651	.24057	.25981			
.128300	.....	.....	.....	.....	*.19245	.21169	.22744		
.115470	.....	.....	.....	.....	.....	*.17321	.18895	.20207	
.104973	.....	.....	.....	.....	.....	.....	*.15746	.17058	.19120
.096225	.....	.....	.....	.....	.....	.....	.....	*.14434	.16496
.082479	.....	.....	.....	.....	.....	.....	.....	.....	*.12372

Wire Sizes	Threads Per Inch									
	8	9	10	11	11½	12	13	14	16	18
.096225	.18042									
.082479	.13918	.15121								
.072169	*.10825	.12028	.12990							
.064150	.....	*.09623	.10585	.11372						
.057735	.....	.....	*.08660	.09448	.09790					
.052486	.....	.....	.....	*.07873	.08215	.08529				
.050204	.....	.....	.....	.....	*.07531	.07844	.08400			
.048113	.....	.....	.....	.....	.....	*.07217	.07772	.08248		
.044412	.....	.....	.....	.....	.....	.....	*.06662	.07138	.07911	
.041239	.....	.....	.....	.....	.....	.....	.....	*.06186	.06959	.07561
.036084	.....	.....	.....	.....	.....	.....	.....	.....	*.05413	.06014
.032074	.....	.....	.....	.....	.....	.....	.....	.....	.....	*.04811

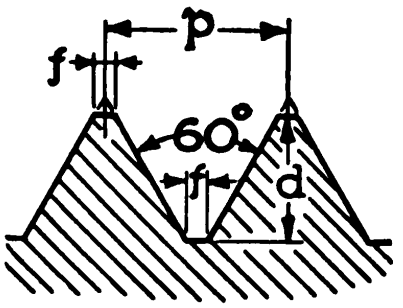
Wire Sizes	Threads Per Inch								
	19	20	22	24	26	27	28	30	32
.036084	.06267								
.032074	.05064	.05292							
.030387	*.04558	.04786	.05180						
.028868	.....	*.04330	.04724	.05052					
.026243	.....	.....	*.03937	.04265	.04542				
.024055	.....	.....	.....	*.03608	.03886	.04009			
.022205	.....	.....	.....	.....	*.03331	.03454	.03569		
.021383	.....	.....	.....	.....	.....	*.03208	.03322	.03528	
.020619	.....	.....	.....	.....	.....	.....	*.03093	.03299	.03480
.019245	.....	.....	.....	.....	.....	.....	.....	*.02887	.03067
.018042	.....	.....	.....	.....	.....	.....	.....	.....	*.02706

Wire Sizes	Threads Per Inch									
	34	36	40	44	48	50	56	64	72	80
.019245	.03226									
.018042	.02866	.03007								
.016980	*.02547	.02689	.02929							
.016037	.....	*.02406	.02646	.02843						
.014434	.....	.....	*.02165	.02362	.02526					
.013121	.....	.....	.....	*.01968	.02132	.02204				
.012028	.....	.....	.....	.....	*.01804	.01876	.02062			
.011547	.....	.....	.....	.....	.....	*.01732	.01918	.02111		
.010310	.....	.....	.....	.....	.....	.....	*.01546	.01740	.01890	
.009021	.....	.....	.....	.....	.....	.....	.....	*.01353	.01504	.01624
.008018	.....	.....	.....	.....	.....	.....	.....	.....	*.01203	.01323
.007217	.....	.....	.....	.....	.....	.....	.....	.....	.....	*.01083

* " Best Size " or Wire touching on pitch Diameter.

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AMERICAN NATIONAL COARSE AND FINE THREAD DIMENSIONS AND TAP DRILL SIZES



$$p = \text{pitch} = \frac{1}{\text{No. of Threads per Inch}}$$

n = Number of threads per inch

$$d = \text{depth} = \text{pitch} \times .649519 \text{ or } \frac{.649519}{n}$$

$$f = \text{flat} = \frac{\text{Pitch}}{8}$$

Nominal Size	Outside Diameter, Inches	Pitch Diameter, Inches	Root Diameter, Inches	Tap Drill	Decimal Equivalent of Tap Drill
*0–80	.0600	.0519	.0438	3/64	.0469
*1–64	.0730	.0629	.0527	53	.0595
72	.0730	.0640	.0550	53	.0595
*2–56	.0860	.0744	.0628	50	.0700
64	.0860	.0759	.0657	50	.0700
*3–48	.0990	.0855	.0719	47	.0785
56	.0990	.0874	.0758	45	.0820
*4–40	.1120	.0958	.0795	43	.0890
48	.1120	.0985	.0849	42	.0935
*5–40	.1250	.1088	.0925	38	.1015
44	.1250	.1102	.0955	37	.1040
*6–32	.1380	.1177	.0974	36	.1065
40	.1380	.1218	.1055	33	.1130
*8–32	.1640	.1437	.1234	29	.1360
36	.1640	.1460	.1279	29	.1360
*10–24	.1900	.1629	.1359	25	.1495
32	.1900	.1697	.1494	21	.1590
*12–24	.2160	.1889	.1619	16	.1770
28	.2160	.1928	.1696	14	.1820
1/4–20	.2500	.2175	.1850	7	.2010
28	.2500	.2268	.2036	3	.2130
5/16–18	.3125	.2764	.2403	F	.2570
24	.3125	.2854	.2584	I	.2720
3/8–16	.3750	.3344	.2938	5/16	.3125
24	.3750	.3479	.3209	Q	.3320
7/16–14	.4375	.3911	.3447	U	.3680
20	.4375	.4050	.3726	25/64	.3906
1/2–13	.5000	.4501	.4001	27/64	.4219
20	.5000	.4675	.4351	29/64	.4531
9/16–12	.5625	.5084	.4542	31/64	.4844
18	.5625	.5264	.4903	33/64	.5156
5/8–11	.6250	.5660	.5069	17/32	.5312
18	.6250	.5889	.5528	37/64	.5781
3/4–10	.7500	.6850	.6201	21/32	.6562
16	.7500	.7094	.6688	11/16	.6875

* American National Standard Wood Screws are made in same numbers and corresponding body diameters as starred sizes.

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AMERICAN NATIONAL COARSE AND FINE THREAD DIMENSIONS AND TAP DRILL SIZES, (*Cont.*)

Nominal Size	Outside Diameter, Inches	Pitch Diameter, Inches	Root Diameter, Inches	Tap Drill	Decimal Equivalent of Tap Drill
7/8– 9	.8750	.8029	.7307	49/64	.7656
14	.8750	.8286	.7822	13/16	.8125
1– 8	1.0000	.9188	.8376	7/8	.8750
14	1.0000	.9536	.9072	15/16	.9375
1 1/8– 7	1.1250	1.0322	.9394	63/64	.9844
12	1.1250	1.0709	1.0168	1 3/64	1.0469
1 1/4– 7	1.2500	1.1572	1.0644	1 7/64	1.1094
12	1.2500	1.1959	1.1418	1 11/64	1.1719
1 3/8– 6	1.3750	1.2667	1.1585	1 7/32	1.2187
12	1.3750	1.3209	1.2668	1 19/64	1.2969
1 1/2– 6	1.5000	1.3917	1.2835	1 11/32	1.3437
12	1.5000	1.4459	1.3918	1 27/64	1.4219
1 3/4– 5	1.7500	1.6201	1.4902	1 9/16	1.5625
2– 4 1/2	2.0000	1.8557	1.7113	1 25/32	1.7812
2 1/4– 4 1/2	2.2500	2.1057	1.9613	2 1/32	2.0312
2 1/2– 4	2.5000	2.3376	2.1752	2 1/4	2.2500
2 3/4– 4	2.7500	2.5876	2.4252	2 1/2	2.5000
3– 4	3.0000	2.8376	2.6752	2 3/4	2.7500
3 1/4– 4	3.2500	3.0876	2.9252	3	3.0000
3 1/2– 4	3.5000	3.3376	3.1752	3 1/4	3.2500
3 3/4– 4	3.7500	3.5876	3.4252	3 1/2	3.5000
4– 4	4.0000	3.8376	3.6752	3 3/4	3.7500

TAP DRILL SIZES FOR AMERICAN NATIONAL PIPE THREAD

Sizes of Pipe, Inches	Number of Threads to Inch	Root Diameter Small End of Pipe and Gage, Inches	Tap Drill	
			Size	Decimal Equivalent
1/8	27	.3339	R	.339
1/4	18	.4329	7/16	.437
3/8	18	.5676	37/64	.578
1/2	14	.7013	23/32	.719
3/4	14	.9105	59/64	.921
1	11 1/2	1.1441	1 5/32	1.156
1 1/4	11 1/2	1.4876	1 1/2	1.500
1 1/2	11 1/2	1.7265	1 47/64	1.734
2	11 1/2	2.1995	2 7/32	2.218
2 1/2	8	2.6195	2 5/8	2.625
3	8	3.2406	3 1/4	3.250
3 1/2	8	3.7375	3 3/4	3.750
4	8	4.2344	4 1/4	4.250

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SHARP V THREAD TAP DRILL SIZES

Size of Tap	No. of Threads	Drill No.	Size of Tap	No. of Threads	Drill No.	Size of Tap	No. of Threads	Drill No.
1/16	60	55	9/64	32	32	13/64	28	20
5/64	60	52	9/64	36	35	13/64	32	20
3/32	48	47	9/64	40	33	7/32	22	19
3/32	56	46	5/32	30	31	7/32	24	18
3/32	60	46	5/32	32	30	7/32	28	17
7/64	32	45	5/32	36	29	7/32	30	15
7/64	36	44	5/32	40	29	7/32	32	13
7/64	40	43	11/64	32	30	15/64	22	10
7/64	44	43	11/64	36	29	15/64	24	10
7/64	48	42	11/64	40	28	15/64	28	9
1/8	32	40	3/16	24	27	15/64	32	9
1/8	36	38	3/16	28	26	1/4	20	7
1/8	40	37	3/16	30	23	1/4	22	5
1/8	44	36	3/16	32	23	1/4	24	2
9/64	30	35	13/64	24	21	1/4	32	2

ACME STANDARD OR 29° THREADS

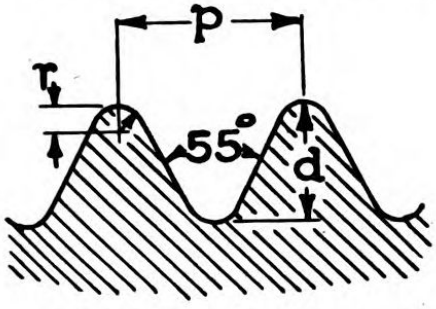
Diameter, Inches	Threads per Inch	Diameter, Inches	Threads per Inch
1/2″	10	1″	6
5/8″	9	1 1/4″	5
3/4″	8	1 1/2″	4
7/8″	7	2″	3

SQUARE THREADS

Diameter, Inches	Threads per Inch	Diameter, Inches	Threads per Inch
1/2″	10	1″	6
5/8″	9	1 1/4″	5
3/4″	8	1 1/2″	4
7/8″	7	2″	3

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British Standard — Whitworth Form
THREAD DIMENSIONS AND TAP DRILL SIZES



p = pitch $\frac{1}{\text{No. thds. per in.}}$

d = depth $= p \times .64033$

r = radius $= p \times .1373$

Nominal Size	Major Diameter Inches	Pitch Diameter Inches	Root Diameter Inches	Commercial Tap Drill to Produce Approximately Full Thread	Decimal Equivalent of Drill
1/16–60	.0625	.0518	.0412	57	.0430
3/32–48	.0938	.0804	.0671	50	.0700
1/8–40	.1250	.1090	.0930	40	.0980
5/32–32	.1563	.1362	.1162	31	.1200
3/16–24	.1875	.1608	.1341	28	.1405
7/32–24	.2188	.1921	.1654	17	.1730
1/4–20	.2500	.2180	.1860	9	.1960
26	.2500	.2254	.2001	4	.2090
9/32–26	.2813	.2566	.2321	C	.2420
5/16–18	.3125	.2769	.2414	1/4	.2500
22	.3125	.2834	.2543	G	.2610
3/8–16	.3750	.3350	.2950	5/16	.3125
20	.3750	.3430	.3110	P	.3230
7/16–14	.4375	.3918	.3460	T	.3580
18	.4375	.4019	.3665	3/8	.3750
1/2–12	.5000	.4466	.3933	Z	.4130
16	.5000	.4600	.4200	7/16	.4375
9/16–12	.5625	.5091	.4558	15/32	.4687
16	.5625	.5225	.4825	1/2	.5000
5/8–11	.6250	.5668	.5086	17/32	.5312
14	.6250	.5793	.5336	35/64	.5469
11/16–11	.6875	.6293	.5711	19/32	.5937
14	.6875	.6418	.5961	39/64	.6094
3/4–10	.7500	.6860	.6219	41/64	.6406
12	.7500	.6966	.6434	21/32	.6562
13/16–10	.8125	.7485	.6844	45/64	.7031
12	.8125	.7591	.7059	23/32	.7187
7/8– 9	.8750	.8039	.7327	3/4	.7500
11	.8750	.8168	.7586	25/32	.7812
15/16– 9	.9375	.8664	.7952	13/16	.8125
1 – 8	1.0000	.9200	.8399	55/64	.8593
10	1.0000	.9360	.8720	57/64	.8906
1 1/8– 7	1.1250	1.0335	.9420	31/32	.9687
9	1.1250	1.0539	.9828	1	1.0000
1 1/4– 7	1.2500	1.1585	1.0670	1 3/32	1.0937
9	1.2500	1.1789	1.1078	1 1/8	1.1250
1 3/8– 6	1.3750	1.2683	1.1616	1 3/16	1.1875
8	1.3750	1.2950	1.2150	1 15/64	1.2343
1 1/2– 6	1.5000	1.3933	1.2866	1 5/16	1.3125
8	1.5000	1.4200	1.3400	1 3/8	1.3750

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British Standard — Whitworth Form
THREAD DIMENSIONS AND TAP DRILL SIZES—(*Continued*)

Nominal Size	Major Diameter Inches	Pitch Diameter Inches	Root Diameter Inches	Commercial Tap Drill to Produce Approximately Full Thread	Decimal Equivalent of Drill
1 5/8–5	1.6250	1.4969	1.3689	1 13/32	1.4062
1 3/4–5	1.7500	1.6219	1.4939	1 17/32	1.5312
1 7/8–4½	1.8750	1.7327	1.5904	1 5/8	1.6250
2 –4½	2.0000	1.8577	1.7154	1 3/4	1.7500
2 1/8–4½	2.1250	1.9827	1.8404	1 7/8	1.8750
2 1/4–4	2.2500	2.0899	1.9298	1 31/32	1.9687
2 3/8–4	2.3750	2.2149	2.0548	2 3/32	2.0937
2 1/2–4	2.5000	2.3399	2.1798	2 7/32	2.2187
2 3/4–3½	2.7500	2.5671	2.3841	2 7/16	2.4375
3 –3½	3.0000	2.8171	2.6341	2 43/64	2.6718
3 1/4–3½	3.2500	3.0530	2.8560	2 7/8	2.8750
3 1/2–3¼	3.5000	3.3030	3.1060	3 1/8	3.1250
3 3/4–3	3.7500	3.5366	3.3231	3 11/32	3.3437
4 –3	4.0000	3.7866	3.5731	3 19/32	3.5937

BROWN & SHARPE 29° WORM THREAD PARTS

	P	D	F	W	T	A	C	S	B
Number of Threads per Inch	Pitch of Single Thread	Depth of Thread	Width of Top of Thread	Width of Space at Bottom	Thickness of Thread at Pitch Line	Thread Above Pitch Line	Clearance at Bottom of Thread	Width of Space at Top	Thickness at Root of Thread
1	1.0	.6866	.3350	.3100	.5000	.3183	.05	.665	.69
1¼	.8	.5492	.2680	.2480	.4000	.2546	.04	.532	.552
1½	.6666	.4577	.2233	.2066	.3333	.2122	.0333	.4433	.4599
2	.5	.3433	.1675	.1550	.2500	.1592	.0250	.3325	.345
2½	.4	.2746	.1340	.1240	.2000	.1273	.0200	.2660	.276
3	.3333	.2289	.1117	.1033	.1666	.1061	.0166	2216	.2299
3½	.2857	.1962	.0957	.0886	.1429	.0909	.0143	.1901	.2011
4	.250	.1716	.0838	.0775	.1250	.0796	.0125	.1637	.1725
4½	.2222	.1526	.0744	.0689	.1111	.0707	.0111	.1478	.1533
5	.2	.1373	.0670	.0620	.1000	.0637	.0100	.1330	.138
6	.1666	.1144	.0559	.0517	.0833	.0531	.0083	.1108	.115
7	.1428	.0981	.0479	.0443	.0714	.0455	.0071	.095	.0985
8	.125	.0858	.0419	.0388	.0625	.0398	.0062	.0818	.0862
9	.1111	.0763	.0372	.0344	.0555	.0354	.0055	.0739	.0766
10	.10	.0687	.0335	.0310	.0500	.0318	.005	.0665	.069
12	.0833	.0572	.0279	.0258	.0416	.0265	.0042	.0551	.0575
16	.0625	.0429	.0209	.0194	.0312	.0199	.0031	.0409	.0431
20	.050	.0343	.0167	.0155	.0250	.0159	.0025	.0332	.0345

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SPEEDS AND FEEDS FOR DRILLING

High Speed Steel Drills

Size of Drill	Feed per Rev.	Bronze, Brass, 300 Feet	Cast Iron, Annealed, 170 Feet	Cast Iron, Hard, 80 Feet	Mild Steel, 120 Feet	Drop Forg., 60 Feet	Mal. Iron, 90 Feet	Tool Steel, 60 Feet	Cast Steel, 40 Feet
Ins.	Ins.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1/16	0.003	....	....	4880	....	3660	....	3660	2440
1/8	0.004	....	5185	2440	3660	1830	2745	1830	1220
3/16	0.005	....	3456	1626	2440	1210	1830	1220	807
1/4	0.006	4575	2593	1220	1830	915	1375	915	610
5/16	0.007	3660	2074	976	1464	732	1138	732	490
3/8	0.008	3050	1728	813	1220	610	915	610	407
7/16	0.009	2614	1482	698	1046	522	784	522	348
1/2	0.010	2287	1296	610	915	458	636	458	305
5/8	0.011	1830	1037	488	732	366	569	366	245
3/4	0.012	1525	864	407	610	305	458	305	203
7/8	0.013	1307	741	349	523	261	392	261	174
1	0.014	1143	648	305	458	229	349	229	153
1 1/4	0.016	915	519	244	366	183	275	183	122
1 1/2	0.016	762	432	204	305	153	212	153	102
1 3/4	0.016	654	371	175	262	131	196	131	87
2	0.016	571	323	153	229	115	172	115	77

Carbon Steel Drills

Size of Drill	Feed per Rev.	Bronze, Brass, 150 Feet	Cast Iron, Annealed, 85 Feet	Cast Iron, Hard, 40 Feet	Mild Steel, 60 Feet	Drop Forg., 30 Feet	Mal. Iron, 45 Feet	Tool Steel, 30 Feet	Cast Steel, 20 Feet
Ins.	Ins.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1/16	0.003	....	5185	2440	3660	1830	2745	1830	1220
1/8	0.004	4575	2593	1220	1840	915	1375	915	610
3/16	0.005	3050	1728	813	1220	610	915	610	407
1/4	0.006	2287	1296	610	915	458	636	458	305
5/16	0.007	1830	1037	488	732	366	569	366	245
3/8	0.008	1525	864	407	610	305	458	305	203
7/16	0.009	1307	741	349	523	261	392	261	174
1/2	0.010	1143	648	305	458	229	343	229	153
5/8	0.011	915	519	244	366	183	275	183	122
3/4	0.012	762	432	204	305	153	212	153	102
7/8	0.013	654	371	175	262	131	196	131	87
1	0.014	571	323	153	229	115	172	115	77
1 1/4	0.016	458	260	122	183	92	138	92	61
1 1/2	0.016	381	216	102	153	77	106	77	51
1 3/4	0.016	327	186	88	131	66	98	66	44
2	0.016	286	162	77	115	58	86	58	39

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TWIST DRILLS
Decimal Equivalents of Letter Size Drills

Letter	Size of Drill in Inches	Letter	Size of Drill in Inches	Letter	Size of Drill in Inches	Letter	Size of Drill in Inches
Z	0.413	S	0.348	L	0.290	E	0.250
Y	0.404	R	0.339	K	0.281	D	0.246
X	0.397	Q	0.332	J	0.277	C	0.242
W	0.386	P	0.323	I	0.272	B	0.238
V	0.377	O	0.316	H	0.266	A	0.234
U	0.368	N	0.302	G	0.261	..	.....
T	0.358	M	0.295	F	0.257	..	.....

TWIST DRILL AND STEEL WIRE GAGE
Decimal Equivalents of Number Size Drills

No.	Size of Drill in Inches	No.	Size of Drill in Inches	No.	Size of Drill in Inches	No.	Size of Drill in Inches
1	0.2280	21	0.1590	41	0.0960	61	0.0390
2	0.2210	22	0.1570	42	0.0935	62	0.0380
3	0.2130	23	0.1540	43	0.0890	63	0.0370
4	0.2090	24	0.1520	44	0.0860	64	0.0360
5	0.2055	25	0.1495	45	0.0820	65	0.0350
6	0.2040	26	0.1470	46	0.0810	66	0.0330
7	0.2010	27	0.1440	47	0.0785	67	0.0320
8	0.1990	28	0.1405	48	0.0760	68	0.0310
9	0.1960	29	0.1360	49	0.0730	69	0.0292
10	0.1935	30	0.1285	50	0.0700	70	0.0280
11	0.1910	31	0.1200	51	0.0670	71	0.0260
12	0.1890	32	0.1160	52	0.0635	72	0.0250
13	0.1850	33	0.1130	53	0.0595	73	0.0240
14	0.1820	34	0.1110	54	0.0550	74	0.0225
15	0.1800	35	0.1100	55	0.0520	75	0.0210
16	0.1770	36	0.1065	56	0.0465	76	0.0200
17	0.1730	37	0.1040	57	0.0430	77	0.0180
18	0.1695	38	0.1015	58	0.0420	78	0.0160
19	0.1660	39	0.0995	59	0.0410	79	0.0145
20	0.1610	40	0.0980	60	0.0400	80	0.0135

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DIFFERENT STANDARDS FOR WIRE GAGES

In use in the United States

Dimensions of Sizes in Decimal Parts of an Inch

Number of Wire Gage	American or Brown & Sharpe	Birmingham, or Stubs' Iron Wire	Washburn & Moen, or Steel Wire Gage	American S.&W. Co.'s Music Wire	Imperial Wire	Stubs' Steel Wire	U. S. Standard Gage for Sheet and Plate Iron and Steel	Number of Wire Gage
00000000	....	....	....	....	....	....	....	00000000
0000000	....	....	.4900	....	....	....	....	0000000
000000	....	....	.4615	.004	.464	....	.46875	000000
00000	....	....	.4305	.005	.432	....	.4375	00000
0000	.460	.454	.3938	.006	.400	....	.40625	0000
000	.40964	.425	.3625	.007	.372	....	.375	000
00	.3648	.380	.3310	.008	.348	....	.34375	00
0	.32486	.340	.3065	.009	.324	....	.3125	0
1	.2893	.300	.2830	.010	.300	.227	.28125	1
2	.25763	.284	.2625	.011	.276	.219	.265625	2
3	.22942	.259	.2437	.012	.252	.212	.250	3
4	.20431	.238	.2253	.013	.232	.207	.234375	4
5	.18194	.220	.2070	.014	.212	.204	.21875	5
6	.16202	.203	.1920	.016	.192	.201	.203125	6
7	.14428	.180	.1770	.018	.176	.199	.1875	7
8	.12849	.165	.1620	.020	.160	.197	.171875	8
9	.11443	.148	.1483	.022	.144	.194	.15625	9
10	.10189	.134	.1350	.024	.128	.191	.140625	10
11	.090742	.120	.1205	.026	.116	.188	.125	11
12	.080808	.109	.1055	.029	.104	.185	.109375	12
13	.071961	.095	.0915	.031	.092	.182	.09375	13
14	.064084	.083	.0800	.033	.080	.180	.078125	14
15	.057068	.072	.0720	.035	.072	.178	.0703125	15
16	.05082	.065	.0625	.037	.064	.175	.0625	16
17	.045257	.058	.0540	.039	.056	.172	.05625	17
18	.040303	.049	.0475	.041	.048	.168	.050	18
19	.03589	.042	.0410	.043	.040	.164	.04375	19
20	.031961	.035	.0348	.045	.036	.161	.0375	20
21	.028462	.032	.0317	.047	.032	.157	.034375	21
22	.025347	.028	.0286	.049	.028	.155	.03125	22
23	.022571	.025	.0258	.051	.024	.153	.028125	23
24	.0201	.022	.0230	.055	.022	.151	.025	24
25	.0179	.020	.0204	.059	.020	.148	.021875	25
26	.01594	.018	.0181	.063	.018	.146	.01875	26
27	.014195	.016	.0173	.067	.0164	.143	.0171875	27
28	.012641	.014	.0162	.071	.0149	.139	.015625	28
29	.011257	.013	.0150	.075	.0136	.134	.0140625	29
30	.010025	.012	.0140	.080	.0124	.127	.0125	30
31	.008928	.010	.0132	.085	.0116	.120	.0109375	31
32	.00795	.009	.0128	.090	.0108	.115	.01015625	32
33	.00708	.008	.0118	.095	.0100	.112	.009375	33
34	.006304	.007	.0104	....	.0092	.110	.00859375	34
35	.005614	.005	.0095	....	.0084	.108	.0078125	35
36	.005	.004	.0090	....	.0076	.106	.00703125	36
37	.004453	....	.0085	....	.0068	.103	.006640625	37
38	.003965	....	.0080	....	.0060	.101	.00625	38
39	.003531	....	.0075	....	.0052	.099	....	39
40	.003141	....	.0070	....	.0048	.097	....	40

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CUTTING SPEEDS

Feet per Minute	15	17.5	20	22.5	25	27.5	30	35	40	45	50	55
Diam., Inches	REVOLUTIONS PER MINUTE											
1-16	917	1070	1222	1375	1528	1681	1833	2139	2445	2750	3056	3361
1-8	458	535	611	688	764	840	917	1070	1222	1375	1528	1681
3-16	306	357	407	458	509	560	611	713	815	917	1019	1120
1-4	229	267	306	344	382	420	458	535	611	688	764	840
5-16	183	214	244	275	306	336	367	428	489	550	611	672
3-8	153	178	204	229	255	280	306	357	407	458	509	560
7-16	131	153	175	196	218	240	262	306	349	393	437	480
1-2	115	134	153	172	191	210	229	267	306	344	382	420
5-8	91.7	107	122	138	153	168	183	214	244	275	306	336
3-4	76.4	89.1	102	115	127	140	153	178	204	229	255	280
7-8	65.5	76.4	87.3	98.2	109	120	131	153	175	196	218	240
1	57.3	66.8	76.4	85.9	95.5	105	115	134	153	172	191	210
1 1-8	50.9	59.4	67.9	76.4	84.9	93.4	102	119	136	153	170	187
1 1-4	45.8	53.5	61.1	68.8	76.4	84.0	91.7	107	122	138	153	168
1 3-8	41.7	48.6	55.6	62.5	69.5	76.4	83.3	97.2	111	125	139	153
1 1-2	38.2	44.6	50.9	57.3	63.7	70.0	76.4	89.1	102	115	127	140
1 5-8	35.3	41.1	47.0	52.9	58.8	64.6	70.5	82.3	94.0	106	118	129
1 3-4	32.7	38.2	43.7	49.1	54.6	60.0	65.5	76.4	87.3	98.2	109	120
1 7-8	30.6	35.7	40.7	45.8	50.9	56.0	61.1	71.3	81.5	91.7	102	112
2	28.7	33.4	38.2	43.0	47.7	52.5	57.3	66.8	76.4	85.9	95.5	105
2 1-4	25.5	29.7	34.0	38.2	42.4	46.7	50.9	59.4	67.9	76.4	84.9	93.4
2 1-2	22.9	26.7	30.6	34.4	38.2	42.0	45.8	53.5	61.1	68.8	76.4	84.0
2 3-4	20.8	24.3	27.8	31.3	34.7	38.2	41.7	48.6	55.6	62.5	69.5	76.4
3	19.1	22.3	25.5	28.6	31.8	35.0	38.2	44.6	50.9	57.3	63.7	70.0
3 1-4	17.6	20.6	23.5	26.4	29.4	32.3	35.3	41.1	47.0	52.9	58.8	64.6
3 1-2	16.4	19.1	21.8	24.5	27.3	30.0	32.7	38.2	43.7	49.1	54.6	60.0
3 3-4	15.3	17.8	20.4	22.9	25.5	28.0	30.6	35.7	40.7	45.8	50.9	56.0
4	14.3	16.7	19.1	21.5	23.9	26.3	28.7	33.4	38.2	43.0	47.7	52.5
4 1-2	12.7	14.9	17.0	19.1	21.2	23.3	25.5	29.7	34.0	38.2	42.4	46.7
5	11.5	13.4	15.3	17.2	19.1	21.0	22.9	26.7	30.6	34.4	38.2	42.0
5 1-2	10.4	12.2	13.9	15.6	17.4	19.1	20.8	24.3	27.8	31.3	34.7	38.2
6	9.5	11.1	12.7	14.3	15.9	17.5	19.1	22.3	25.5	28.6	31.8	35.0
6 1-2	8.8	10.3	11.8	13.2	14.7	16.2	17.6	20.6	23.5	26.4	29.4	32.3
7	8.2	9.5	10.9	12.3	13.6	15.0	16.4	19.1	21.8	24.5	27.3	30.0
7 1-2	7.6	8.9	10.2	11.5	12.7	14.0	15.3	17.8	20.4	22.9	25.5	28.0
8	7.2	8.4	9.5	10.7	11.9	13.1	14.3	16.7	19.1	21.5	23.9	26.3
8 1-2	6.7	7.9	9.0	10.1	11.2	12.4	13.5	15.7	18.0	20.2	22.5	24.7
9	6.4	7.4	8.5	9.5	10.6	11.7	12.7	14.9	17.0	19.1	21.2	23.3
9 1-2	6.0	7.0	8.0	9.1	10.1	11.1	12.1	14.1	16.1	18.1	20.1	22.1
10	5.7	6.7	7.6	8.6	9.5	10.5	11.5	13.4	15.3	17.2	19.1	21.0
11	5.2	6.1	6.9	7.8	8.7	9.5	10.4	12.2	13.9	15.6	17.4	19.1
12	4.8	5.6	6.4	7.2	8.0	8.8	9.5	11.1	12.7	14.3	15.9	17.5
13	4.4	5.1	5.9	6.6	7.3	8.1	8.8	10.3	11.8	13.2	14.7	16.2
14	4.1	4.8	5.5	6.1	6.8	7.5	8.2	9.5	10.9	12.3	13.6	15.0
15	3.8	4.5	5.1	5.7	6.4	7.0	7.6	8.9	10.2	11.5	12.7	14.0
16	3.6	4.2	4.8	5.4	6.0	6.6	7.2	8.4	9.5	10.7	11.9	13.1
17	3.4	3.9	4.5	5.1	5.6	6.2	6.7	7.9	9.0	10.1	11.2	12.4
18	3.2	3.7	4.2	4.8	5.3	5.8	6.4	7.4	8.5	9.5	10.6	11.7
Feet per Minute	15	17.5	20	22.5	25	27.5	30	35	40	45	50	55

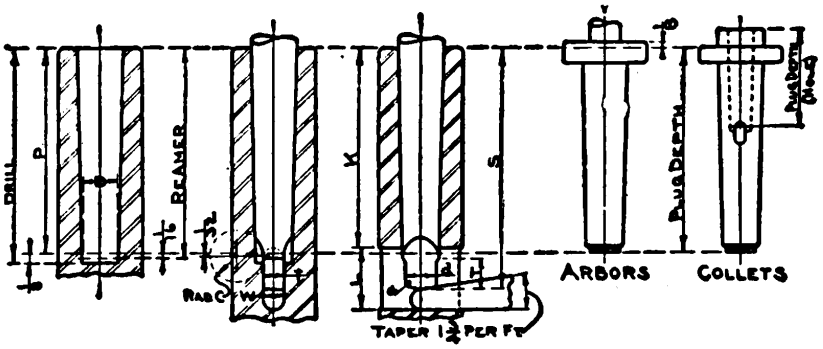
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CUTTING SPEEDS (*Continued*)

Feet per Minute	60	65	70	75	80	90	100	110	120	130	140	150
Diam., Inches	REVOLUTIONS PER MINUTE											
1-16	3667	3973	4278	4584	4889	...	...	...	...	...	...	...
1-8	1833	1986	2139	2292	2445	2750	3056	3361	3667	3973	4278	4584
3-16	1222	1324	1426	1528	1630	1833	2037	2241	2445	2648	2852	3056
1-4	917	993	1070	1146	1222	1375	1528	1681	1833	1986	2139	2292
5-16	733	794	856	917	978	1100	1222	1345	1467	1589	1711	1833
3-8	611	662	713	764	815	917	1019	1120	1222	1324	1426	1528
7-16	524	568	611	655	698	786	873	960	1048	1135	1222	1310
1-2	458	497	535	573	611	688	764	840	917	993	1070	1146
5-8	367	397	428	458	489	550	611	672	733	794	856	917
3-4	306	331	357	382	407	458	509	560	611	662	713	764
7-8	262	284	306	327	349	393	437	480	524	568	611	655
1	229	248	267	287	306	344	382	420	458	497	535	573
1 1-8	204	221	238	255	272	306	340	373	407	441	475	509
1 1-4	183	199	214	229	244	275	306	336	367	397	428	458
1 3-8	167	181	194	208	222	250	278	306	333	361	389	417
1 1-2	153	166	178	191	204	229	255	280	306	331	357	382
1 5-8	141	153	165	176	188	212	235	259	282	306	329	353
1 3-4	131	142	153	164	175	196	218	240	262	284	306	327
1 7-8	122	132	143	153	163	183	204	224	244	265	285	306
2	115	124	134	143	153	172	191	210	229	248	267	287
2 1-4	102	110	119	127	136	153	170	187	204	221	238	255
2 1-2	91.7	99.3	107	115	122	138	153	168	183	199	214	229
2 3-4	83.3	90.3	97.2	104	111	125	139	153	167	181	194	208
3	76.4	82.8	89.1	95.5	102	115	127	140	153	166	178	191
3 1-4	70.5	76.4	82.3	88.2	94.0	106	118	129	141	153	165	176
3 1-2	65.5	70.9	76.4	81.9	87.3	98.2	109	120	131	142	153	164
3 3-4	61.1	66.2	71.3	76.4	81.5	91.7	102	112	122	132	143	153
4	57.3	62.1	66.8	71.6	76.4	85.9	95.5	105	115	124	134	143
4 1-2	50.9	55.2	59.4	63.6	67.9	76.4	84.9	93.4	102	110	119	127
5	45.8	49.7	53.5	57.3	61.1	68.8	76.4	84.0	91.7	99.3	107	115
5 1-2	41.7	45.1	48.6	52.1	55.6	62.5	69.5	76.4	83.3	90.3	97.2	104
6	38.2	41.4	44.6	47.8	50.9	57.3	63.7	70.0	76.4	82.8	89.1	95.5
6 1-2	35.3	38.2	41.1	44.1	47.0	52.9	58.8	64.6	70.5	76.4	82.3	88.2
7	32.7	35.5	38.2	40.9	43.7	49.1	54.6	60.0	65.5	70.9	76.4	81.9
7 1-2	30.6	33.1	35.7	38.2	40.7	45.8	50.9	56.0	61.1	66.2	71.3	76.4
8	28.7	31.0	33.4	35.8	38.2	43.0	47.7	52.5	57.3	62.1	66.8	71.6
8 1-2	27.0	29.2	31.5	33.7	36.0	40.4	44.9	49.4	53.9	58.4	62.9	67.4
9	25.5	27.6	29.7	31.8	34.0	38.2	42.4	46.7	50.9	55.2	59.4	63.6
9 1-2	24.1	26.1	28.2	30.2	32.2	36.2	40.2	44.2	48.3	52.3	56.3	60.3
10	22.9	24.8	26.7	28.7	30.6	34.4	38.2	42.0	45.8	49.7	53.5	57.3
11	20.8	22.6	24.3	26.0	27.8	31.3	34.7	38.2	41.7	45.1	48.6	52.1
12	19.1	20.7	22.3	23.9	25.5	28.6	31.8	35.0	38.2	41.4	44.6	47.8
13	17.6	19.1	20.6	22.0	23.5	26.4	29.4	32.3	35.3	38.2	41.1	44.1
14	16.4	17.7	19.1	20.5	21.8	24.5	27.3	30.0	32.7	35.5	38.2	40.9
15	15.3	16.6	17.8	19.1	20.4	22.9	25.5	28.0	30.6	33.1	35.7	38.2
16	14.3	15.5	16.7	17.9	19.1	21.5	23.9	26.3	28.7	31.0	33.4	35.8
17	13.5	14.6	15.7	16.9	18.0	20.2	22.5	24.7	27.0	29.2	31.5	33.7
18	12.7	13.8	14.9	15.9	17.0	19.1	21.2	23.3	25.5	27.6	29.7	31.8
Feet per Minute	60	65	70	75	80	90	100	110	120	130	140	150

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BROWN & SHARPE TAPERS



Taper approximates 1-2" per ft. except No. 10 which is .5161" per ft.

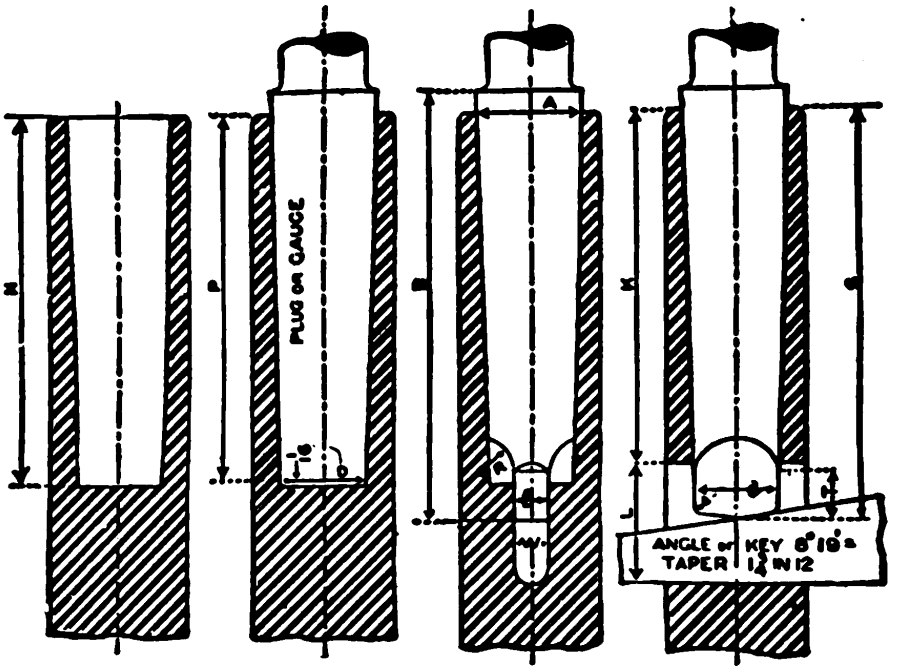
No. of Taper	Diam. of Plug at Small End D	Plug Depth P: B & S* Standard	Plug Depth P: Mill. Mach. Standard	Plug Depth P: Miscell.	Keyway from End of Spindle K	Shank Depth S	Length of Keyway† L	Width of Keyway W	Length of Arbor Tongue T	Diameter of Arbor Tongue d	Thickness of Arbor Tongue t	Radius of Tongue Circle c	Radius of Tongue at a	Limit for Tongue—to project thru Test Tool
1	.200	15/16			15/16	1 3/16	3/8	.135	3/16	.170	1/8	3/16	.030	.003
2	.250	1 3/16			1 11/64	1 1/2	1/2	.166	1/4	.220	5/32	3/16	.030	.003
3	.312	1 1/2			1 15/32	1 7/8	5/8	.197	5/16	.282	3/16	3/16	.040	.003
				1 3/4	1 23/32	2 1/8	5/8	.197	5/16	.282	3/16	3/16	.040	.003
				2	1 31/32	2 3/8	5/8	.197	5/16	.282	3/16	3/16	.040	.003
4	.350		1 1/4		1 13/64	1 21/32	11/16	.228	11/32	.320	7/32	5/16	.050	.003
		1 11/16			1 41/64	2 3/32	11/16	.228	11/32	.320	7/32	5/16	.050	.003
5	.450		1 3/4		1 11/16	2 3/16	3/4	.260	3/8	.420	1/4	5/16	.060	.003
				2	1 15/16	2 7/16	3/4	.260	3/8	.420	1/4	5/16	.060	.003
		2 1/8			2 1/16	2 9/16	3/4	.260	3/8	.420	1/4	5/16	.060	.003
6	.500	2 3/8			2 19/64	2 7/8	7/8	.291	7/16	.460	9/32	5/16	.060	.005
7	.600			2 1/2	2 13/32	3 1/32	15/16	.322	15/32	.560	5/16	3/8	.070	.005
		2 7/8			2 25/32	3 13/32	15/16	.322	15/32	.560	5/16	3/8	.070	.005
			3		2 29/32	3 17/32	15/16	.322	15/32	.560	5/16	3/8	.070	.005
8	.750	3 9/16			3 29/64	4 1/16	1	.353	1/2	.710	11/32	3/8	.080	.005
9	.900		4		3 7/8	4 5/8	1 1/8	.385	9/16	.860	3/8	7/16	.100	.005
		4 1/4			4 1/8	4 7/8	1 1/8	.385	9/16	.860	3/8	7/16	.100	.005
10	1.0446	5			4 27/32	5 23/32	1 5/16	.447	21/32	1.010	7/16	7/16	.110	.005
			5 11/16		5 17/32	6 13/32	1 5/16	.447	21/32	1.010	7/16	7/16	.110	.005
				6 7/32	6 1/16	6 15/16	1 5/16	.447	21/32	1.010	7/16	7/16	.110	.005
11	1.250	5 15/16			5 25/32	6 21/32	1 5/16	.447	21/32	1.210	7/16	1/2	.130	.005
			6 3/4		6 19/32	7 15/32	1 5/16	.447	21/32	1.210	7/16	1/2	.130	.005
12	1.500	7 1/8	7 1/8		6 15/16	7 15/16	1 1/2	.510	3/4	1.460	1/2	1/2	.150	.005
				6 1/4										
13	1.750	7 3/4			7 9/16	8 9/16	1 1/2	.510	3/4	1.710	1/2	5/8	.170	.010
14	2.00	8 1/4	8 1/4		8 1/32	9 5/32	1 11/16	.572	27/32	1.960	9/16	3/4	.190	.010
15	2.25	8 3/4			8 17/32	9 21/32	1 11/16	.572	27/32	2.210	9/16	7/8	.210	.010
16	2.50	9 1/4			9	10 1/4	1 7/8	.635	15/16	2.450	5/8	1	.230	.010
17	2.75	9 3/4												
18	3.00	10 1/4												

*"B & S Standard" Plug Depths are not used in all cases.

†Special lengths of keyway are used instead of standard lengths in some places. Standard lengths need not be used when keyway is for driving only and not for admitting key to force out tool.

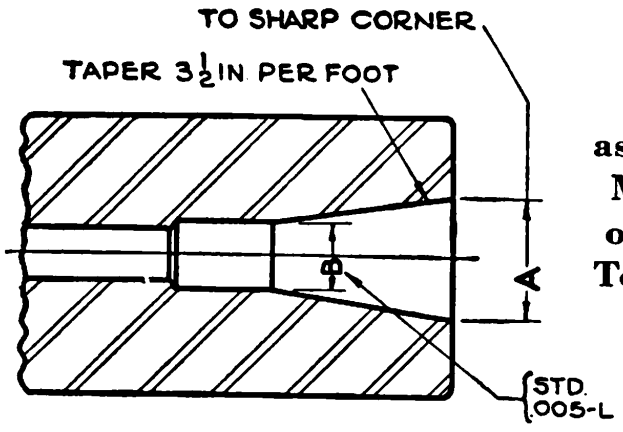
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MORSE TAPERS



Number of Taper	Diam. of Plug at Small End, Inches	Diam. at End of Socket, Inches	SHANK		Depth of Hole, Inches	Standard Plug Depth, Inches	TONGUE					KEYWAY			Taper per Foot	Taper per Inch	Number of Key
			Whole Length of Shank, Inches	Shank Depth, Inches			Thickness of Tongue, Inches	Length of Tongue, Inches	Rad. of Mill for Tongue, Inches	Diameter of Tongue, Inches	Radius of Tongue, Inches	Width of Keyway, Inches	Length of Keyway, Inches	End of Socket to Keyway, Inches			
	D	A	B	S	H	P	t	T	R	d	a	W	L	K			
0	.252	.3561	2 11/16	2 1/32	2 1/32	2	1/32	1/4	1/32	.235	.04	.160	5/32	1 11/16	.62460	.05205	0
1	.369	.475	2 5/16	2 1/16	2 1/16	2 1/8	1/16	5/16	1/16	.343	.05	.213	3/4	2 1/16	.59858	.04988	1
2	.572	.700	3 1/8	2 11/16	2 5/8	2 1/16	1/4	1/16	1/4	1/16	.06	.260	7/8	2 1/2	.59941	.04995	2
3	.778	.938	3 7/8	3 11/16	3 1/4	3 1/16	1/16	1/16	3/32	1/16	.08	.322	1 1/16	3 1/16	.60235	.05019	3
4	1.020	1.231	4 7/8	4 5/8	4 1/8	4 1/16	1/16	5/8	1/16	1/16	.10	.478	1 1/4	3 7/8	.62326	.05193	4
5	1.475	1.748	6 1/8	5 7/8	5 1/4	5 1/16	5/8	3/4	3/8	1 11/16	.12	.635	1 1/2	4 11/16	.63151	.05262	5
6	2.116	2.494	8 1/16	8 1/4	7 3/8	7 1/4	3/4	1 1/8	1/2	2	.15	.760	1 3/4	7	.62565	.05213	6
7	2.750	3.270	11 5/16	11 1/4	10 1/8	10	1 1/8	1 3/8	3/4	2 5/8	.18	1.135	2 5/8	9 1/2	.62400	.05200	7

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MILLING MACHINE STANDARD TAPERS

as adopted by the Milling Machine Manufacturers of the National Machine Tool Builders' Association

No. of Taper	A	B	*Threaded End of Draw-In Bolt
10	5/8	3/8	
20	7/8	1/2	
30	1 1/4	5/8	
40	1 3/4	1	7/16" 14 N.C., R.H. 5/8" 11 N.C., R.H.
50	2 3/4	1 9/16	5/8" 11 N.C., R.H. 1" 8 N.C., R.H.

* End of Draw-In Bolt is threaded with two sizes of thread. The larger size thread is used in threaded hole in Arbors and in Adapters where possible, but limitations on certain Adapters require the use of a threaded hole to fit the smaller Threaded End of the Draw-In Bolt.

THE JARNO TAPER

Taper per Foot = 0.6 Inch Taper per Inch = 0.05 Inch.

$$\text{Diam. Large End} = \frac{\text{No. of Taper}}{8} \qquad \text{Diam. Small End} = \frac{\text{No. of Taper}}{10}$$

$$\text{Length of Taper} = \frac{\text{No. of Taper}}{2}$$

In the Jarno system, the taper of which is 0.6 inch per foot or 1 in 20, the number of the taper is the key by which all the dimensions are immediately determined. That is, the number of the taper is the number of tenths of an inch in diameter at the small end, the number of eighths of an inch at the large end, and the number of halves of an inch in length or depth. For example: the No. 6 taper is six-eighths (3/4) inch diameter at large end, six-tenths (6/10) inch diameter at the small end and six-halves (3) inches in length. Similarly, the No. 16 taper is sixteen-eighths, or 2 inches diameter at the large end; sixteen-tenths or 1.6 inches at the small end and sixteen-halves or 8 inches in length.

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TAPERS FROM 1/16 TO 1¼ INCH PER FOOT

Amount of Taper for Lengths up to 24 Inches

Length Tapered, Inches	Taper per Foot									
	1/16	3/32	1/8	1/4	3/8	1/2	5/8	3/4	1	1¼
1/32	.0002	.0002	.0003	.0007	.0010	.0013	.0016	.0020	.0026	.0033
1/16	.0003	.0005	.0007	.0013	.0020	.0026	.0033	.0039	.0052	.0065
1/8	.0007	.0010	.0013	.0026	.0039	.0052	.0065	.0078	.0104	.0130
5/16	.0010	.0015	.0020	.0039	.0059	.0078	.0098	.0117	.0156	.0195
1/4	.0013	.0020	.0026	.0052	.0078	.0104	.0130	.0156	.0208	0260
5/16	.0016	.0024	.0033	.0065	.0098	.0130	.0163	.0195	.0260	.0326
3/8	.0020	.0029	.0039	.0078	.0117	.0156	.0195	.0234	.0312	.0391
7/16	.0023	.0034	.0046	.0091	.0137	.0182	.0228	.0273	.0365	.0456
1/2	.0026	.0039	.0052	.0104	.0156	.0208	.0260	.0312	.0417	.0521
9/16	.0029	.0044	.0059	.0117	.0176	.0234	.0293	.0352	.0469	.0586
5/8	.0033	.0049	.0065	.0130	.0195	.0260	.0326	.0391	.0521	.0651
11/16	.0036	.0054	.0072	.0143	.0215	.0286	.0358	.0430	.0573	.0716
3/4	.0039	.0059	.0078	.0156	.0234	.0312	.0391	.0469	.0625	.0781
13/16	.0042	.0063	.0085	.0169	.0254	.0339	.0423	.0508	.0677	.0846
7/8	.0046	.0068	.0091	.0182	.0273	.0365	.0456	.0547	.0729	.0911
15/16	.0049	.0073	.0098	.0195	.0293	.0391	.0488	.0586	.0781	.0977
1	.0052	.0078	.0104	.0208	.0312	.0417	.0521	.0625	.0833	.1042
2	.0104	.0156	.0208	.0417	.0625	.0833	.1042	.125	.1667	.2083
3	.0156	.0234	.0312	.0625	.0937	.1250	.1562	.1875	.250	.3125
4	.0208	.0312	.0417	.0833	.125	.1667	.2083	.250	.3333	.4167
5	.0260	.0391	.0521	.1042	.1562	.2083	.2604	.3125	.4167	.5208
6	.0312	.0469	.0625	.125	.1875	.250	.3125	.375	.500	.625
7	.0365	.0547	.0729	.1458	.2187	.2917	.3646	.4375	.5833	.7292
8	.0417	.0625	.0833	.1667	.250	.3333	.4167	.500	.6667	.8333
9	.0469	.0703	.0937	.1875	.2812	.375	.4687	.5625	.750	.9375
10	.0521	.0781	.1042	.2083	.3125	.4167	.5208	.625	.8333	1.0417
11	.0573	.0859	.1146	.2292	.3437	.4583	.5729	.6875	.9167	1.1458
12	.0625	.0937	.125	.250	.375	.500	.625	.750	1.000	1.250
13	.0677	.1016	.1354	.2708	.4062	.5417	.6771	.8125	1.0833	1.3542
14	.0729	.1094	.1458	.2917	.4375	.5833	.7292	.875	1.1667	1.4583
15	.0781	.1172	.1562	.3125	.4687	.625	.7812	.9375	1.250	1.5625
16	.0833	.125	.1667	.3333	.500	.6667	.8333	1.000	1.3333	1.6667
17	.0885	.1328	.1771	.3542	.5312	.7083	.8854	1.0625	1.4167	1.7708
18	.0937	.1406	.1875	.3750	.5625	.750	.9375	1.125	1.500	1.875
19	.0990	.1484	.1979	.3958	.5937	.7917	.9896	1.1875	1.5833	1.9792
20	.1042	.1562	.2083	.4167	.625	.8333	1.0417	1.250	1.6667	2.0833
21	.1094	.1641	.2187	.4375	.6562	.875	1.0937	1.3125	1.750	2.1875
22	.1146	.1719	.2292	.4583	.6875	.9167	1.1458	1.375	1.8333	2.2917
23	.1198	.1797	.2396	.4792	.7187	.9583	1.1970	1.4375	1.9167	2.3958
24	.125	.1875	.250	.500	.750	1.000	1.250	1.500	2.000	2.500

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AREAS AND CIRCUMFERENCES OF CIRCLES FROM 1/32 TO 10

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
1/32	0.00077	0.098175	2	3.1416	6.28319	5	19.635	15.7080
3/64	0.00173	0.147262	1/16	3.3410	6.47953	1/16	20.129	15.9043
1/16	0.00307	0.196350	1/8	3.5466	6.67588	1/8	20.629	16.1007
3/32	0.00690	0.294524	3/16	3.7583	6.87223	3/16	21.135	16.2970
1/8	0.01227	0.392699	1/4	3.9761	7.06858	1/4	21.648	16.4934
5/32	0.01917	0.490874	5/16	4.2000	7.26493	5/16	22.166	16.6897
3/16	0.02761	0.589049	3/8	4.4301	7.46128	3/8	22.691	16.8861
7/32	0.03758	0.687223	7/16	4.6664	7.65763	7/16	23.221	17.0824
1/4	0.04909	0.785398	1/2	4.9087	7.85398	1/2	23.758	17.2788
9/32	0.06213	0.883573	9/16	5.1572	8.05033	9/16	24.301	17.4751
5/16	0.07670	0.981748	5/8	5.4119	8.24668	5/8	24.850	17.6715
11/32	0.09281	1.07992	11/16	5.6727	8.44303	11/16	25.406	17.8678
3/8	0.11045	1.17810	3/4	5.9396	8.63938	3/4	25.967	18.0642
13/32	0.12962	1.27627	13/16	6.2126	8.83573	13/16	26.535	18.2605
7/16	0.15033	1.37445	7/8	6.4918	9.03208	7/8	27.109	18.4569
15/32	0.17257	1.47262	15/16	6.7771	9.22843	15/16	27.688	18.6532
1/2	0.19635	1.57080	3	7.0686	9.42478	6	28.274	18.8496
17/32	0.22166	1.66897	1/16	7.3662	9.62113	1/8	29.465	19.2423
9/16	0.24850	1.76715	1/8	7.6699	9.81748	1/4	30.680	19.6350
19/32	0.27688	1.86532	3/16	7.9798	10.0138	3/8	31.919	20.0277
5/8	0.30680	1.96350	1/4	8.2958	10.2102	1/2	33.183	20.4204
21/32	0.33824	2.06167	5/16	8.6179	10.4065	5/8	34.472	20.8131
11/16	0.37122	2.15984	3/8	8.9462	10.6029	3/4	35.785	21.2058
23/32	0.40574	2.25802	7/16	9.2806	10.7992	7/8	37.122	21.5984
3/4	0.44179	2.35619	1/2	9.6211	10.9956	7	38.485	21.9911
25/32	0.47937	2.45437	9/16	9.9678	11.1919	1/8	39.871	22.3838
13/16	0.51849	2.55254	5/8	10.321	11.3883	1/4	41.282	22.7765
27/32	0.55914	2.65072	11/16	10.680	11.5846	3/8	42.718	23.1692
7/8	0.60132	2.74889	3/4	11.045	11.7810	1/2	44.179	23.5619
29/32	0.64504	2.84707	13/16	11.416	11.9773	5/8	45.664	23.9546
15/16	0.69029	2.94524	7/8	11.793	12.1737	3/4	47.173	24.3473
31/32	0.73708	3.04342	15/16	12.177	12.3700	7/8	48.707	24.7400
1	0.78540	3.14159	4	12.566	12.5664	8	50.265	25.1327
1/16	0.88664	3.33794	1/16	12.962	12.7627	1/8	51.849	25.5224
1/8	0.99402	3.53429	1/8	13.364	12.9591	1/4	53.456	25.9181
3/16	1.1075	3.73064	3/16	13.772	13.1554	3/8	55.088	26.3108
1/4	1.2272	3.92699	1/4	14.186	13.3518	1/2	56.745	26.7035
5/16	1.3530	4.12334	5/16	14.607	13.5481	5/8	58.426	27.0962
3/8	1.4849	4.31969	3/8	15.033	13.7445	3/4	60.132	27.4889
7/16	1.6230	4.51604	7/16	15.466	13.9408	7/8	61.862	27.8816
1/2	1.7671	4.71239	1/2	15.904	14.1372	9	63.617	28.2743
9/16	1.9175	4.90874	9/16	16.349	14.3335	1/8	65.397	28.6670
5/8	2.0739	5.10509	5/8	16.800	14.5299	1/4	67.201	29.0597
11/16	2.2365	5.30144	11/16	17.257	14.7262	3/8	69.029	29.4524
3/4	2.4053	5.49779	3/4	17.721	14.9226	1/2	70.882	29.8451
13/16	2.5802	5.69414	13/16	18.190	15.1189	5/8	72.760	30.2378
7/8	2.7612	5.89049	7/8	18.665	15.3153	3/4	74.662	30.6305
15/16	2.9483	6.08684	15/16	19.147	15.5116	7/8	76.589	31.0232

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LENGTHS OF CHORDS FOR SPACING OFF THE CIRCUMFERENCE OF CIRCLES WITH A DIAMETER EQUAL TO 1

For Circles of Other Diameters Multiply Length Given in Table by Diameter of Circle

No. of Spaces	Length of Chord	No. of Spaces	Length of Chord	No. of Spaces	Length of Chord	No. of Spaces	Length of Chord	No. of Spaces	Length of Chord
3	0.8660	23	0.1362	43	0.0730	63	0.0499	83	0.0378
4	0.7071	24	0.1305	44	0.0713	64	0.0491	84	0.0374
5	0.5878	25	0.1253	45	0.0698	65	0.0483	85	0.0370
6	0.5000	26	0.1205	46	0.0682	66	0.0476	86	0.0365
7	0.4339	27	0.1161	47	0.0668	67	0.0469	87	0.0361
8	0.3827	28	0.1120	48	0.0654	68	0.0462	88	0.0357
9	0.3420	29	0.1081	49	0.0641	69	0.0455	89	0.0353
10	0.3090	30	0.1045	50	0.0628	70	0.0449	90	0.0349
11	0.2818	31	0.1012	51	0.0616	71	0.0442	91	0.0345
12	0.2588	32	0.0980	52	0.0604	72	0.0436	92	0.0341
13	0.2393	33	0.0951	53	0.0592	73	0.0430	93	0.0338
14	0.2224	34	0.0923	54	0.0581	74	0.0424	94	0.0334
15	0.2079	35	0.0896	55	0.0571	75	0.0419	95	0.0331
16	0.1951	36	0.0872	56	0.0561	76	0.0413	96	0.0327
17	0.1837	37	0.0848	57	0.0551	77	0.0408	97	0.0324
18	0.1736	38	0.0826	58	0.0541	78	0.0403	98	0.0321
19	0.1645	39	0.0805	59	0.0532	79	0.0398	99	0.0317
20	0.1564	40	0.0785	60	0.0523	80	0.0393	100	0.0314
21	0.1490	41	0.0765	61	0.0515	81	0.0388	....	....
22	0.1423	42	0.0747	62	0.0507	82	0.0383	....	....

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WEIGHT OF SQUARE AND ROUND BARS OF STEEL

In Pounds per Linear Foot

Based on 489.6 lbs. per cubic foot. For Wrought Iron deduct 2 per cent. For High Speed Steel add 10 per cent.

Thickness or Diameter, Inches	Weight of Square Bar 1 foot long	Weight of Round Bar 1 foot long	Thickness or Diameter, Inches	Weight of Square Bar 1 foot long	Weight of Round Bar 1 foot long
1/32	.0033	.0026	2 1/2	21.25	16.69
1/16	.0133	.0104	9/16	22.33	17.53
1/8	.0531	.0417	5/8	23.43	18.40
3/16	.1195	.0938	11/16	24.56	19.29
1/4	.2123	.1669	3/4	25.00	20.20
5/16	.3333	.2608	13/16	26.90	21.12
3/8	.4782	.3756	7/8	28.10	22.07
7/16	.6508	.5111	15/16	29.34	23.04
1/2	.8500	.6676	3	30.60	24.03
9/16	1.076	.8449	1/16	31.89	25.04
5/8	1.328	1.043	1/8	33.20	26.08
11/16	1.608	1.262	3/16	34.55	27.13
3/4	1.913	1.502	1/4	35.92	28.20
13/16	2.245	1.763	5/16	37.31	29.30
7/8	2.603	2.044	3/8	38.73	30.42
15/16	2.989	2.347	7/16	40.18	31.56
1	3.400	2.670	1/2	41.65	32.71
1/16	3.838	3.014	9/16	43.14	33.90
1/8	4.303	3.379	5/8	44.68	35.09
3/16	4.795	3.766	11/16	46.24	36.31
1/4	5.312	4.173	3/4	47.82	37.56
5/16	5.857	4.600	13/16	49.42	38.81
3/8	6.428	5.019	7/8	51.05	40.10
7/16	7.026	5.518	15/16	52.71	41.40
1/2	7.650	6.008	4	54.40	42.73
9/16	8.301	6.520	1/16	56.11	44.07
5/8	8.978	7.051	1/8	57.85	45.44
11/16	9.682	7.604	3/16	59.62	46.83
3/4	10.41	8.178	1/4	61.41	48.24
13/16	11.17	8.773	5/16	63.23	49.66
7/8	11.95	9.388	3/8	65.08	51.11
15/16	12.76	10.02	7/16	66.95	52.58
2	13.60	10.68	1/2	68.85	54.07
1/16	14.46	11.36	9/16	70.78	55.59
1/8	15.35	12.06	5/8	73.73	57.12
3/16	16.27	12.78	11/16	74.70	58.67
1/4	17.22	13.52	3/4	76.71	60.25
5/16	18.19	14.28	13/16	78.74	61.84
3/8	19.18	15.07	7/8	80.81	63.46
7/16	20.20	15.86	15/16	82.89	65.10

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WEIGHT OF SQUARE AND ROUND BARS OF STEEL
In Pounds per Linear Foot (*Continued*)

Thickness or Diameter, Inches	Weight of Square Bar 1 foot long	Weight of Round Bar 1 foot long	Thickness or Diameter, Inches	Weight of Square Bar 1 foot long	Weight of Round Bar 1 foot long
5	85.00	66.76	7	166.6	130.9
1/16	87.14	68.44	1/8	172.6	135.6
1/8	89.30	70.14	1/4	178.7	140.4
3/16	91.49	71.86	3/8	184.9	145.3
1/4	93.72	73.60	1/2	191.3	150.2
5/16	95.96	75.37	5/8	197.7	155.2
3/8	98.23	77.15	3/4	204.2	160.3
7/16	100.5	78.95	7/8	210.8	165.6
1/2	102.8	80.77	8	217.6	171.0
9/16	105.2	82.62	1/8	224.5	176.3
5/8	107.6	84.49	1/4	231.4	181.8
11/16	110.0	86.38	3/8	238.5	187.3
3/4	112.4	88.29	1/2	245.6	193.0
13/16	114.9	90.22	5/8	252.9	198.7
7/8	117.4	92.17	3/4	260.3	204.4
15/16	119.9	94.14	7/8	267.9	210.3
6	122.4	96.14	9	275.4	216.3
1/16	125.0	98.14	1/8	283.2	222.4
1/8	127.6	100.2	1/4	291.1	228.5
3/16	130.2	102.2	3/8	298.9	234.7
1/4	132.8	104.3	1/2	306.8	241.0
5/16	135.5	106.4	5/8	315.0	247.4
3/8	138.2	108.5	3/4	323.2	253.9
7/16	140.9	110.7	7/8	331.6	260.4
1/2	143.6	112.8	10	340.0	267.0
9/16	146.5	114.9	1/4	357.2	280.6
5/8	149.2	117.2	1/2	374.9	294.4
11/16	152.1	119.4	3/4	392.9	308.6
3/4	154.9	121.7	11	411.4	323.1
13/16	157.8	123.9	1/4	430.3	337.9
7/8	160.8	126.2	1/2	449.6	353.1
15/16	163.6	128.5	3/4	469.4	368.6

To compute the weight of Sheet Steel:

Multiply the thickness by 40.8; the result is the weight in pounds per square foot.

Example: A piece of Sheet Steel is .005″ thick, its weight is .005 × 40.8 = .204 lb. per square foot.

To compute the weight of Sheet Iron:

Multiply the thickness by 40; the result is the weight in pounds per square foot.

Example: A piece of Sheet Iron is .005″ thick, its weight is .005 × 40 = .200 lb. per square foot.

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WEIGHT OF IRON AND STEEL SHEETS

Thickness by Birmingham Gage				Thickness by American (Brown & Sharpe's) Gage			
No. of Gage	Thickness, Inches	Weight per Sq. Ft.		No. of Gage	Thickness, Inches	Weight per Sq. Ft.	
		Iron	Steel			Iron	Steel
0000	.454	18.16	18.52	0000	.46	18.40	18.77
000	.425	17.00	17.34	000	.4096	16.38	16.71
00	.38	15.20	15.50	00	.3648	14.59	14.88
0	.34	13.60	13.87	0	.3249	13.00	13.26
1	.3	12.00	12.24	1	.2893	11.57	11.80
2	.284	11.36	11.59	2	.2576	10.30	10.51
3	.259	10.36	10.57	3	.2294	9.18	9.36
4	.238	9.52	9.71	4	.2043	8.17	8.34
5	.22	8.80	8.98	5	.1819	7.28	7.42
6	.203	8.12	8.28	6	.1620	6.48	6.61
7	.18	7.20	7.34	7	.1443	5.77	5.89
8	.165	6.60	6.73	8	.1285	5.14	5.24
9	.148	5.92	6.04	9	.1144	4.58	4.67
10	.134	5.36	5.47	10	.1019	4.08	4.16
11	.12	4.80	4.90	11	.0907	3.63	3.70
12	.109	4.36	4.45	12	.0808	3.23	3.30
13	.095	3.80	3.88	13	.0720	2.88	2.94
14	.083	3.32	3.39	14	.0641	2.56	2.62
15	.072	2.88	2.94	15	.0571	2.28	2.33
16	.065	2.60	2.65	16	.0508	2.03	2.07
17	.058	2.32	2.37	17	.0453	1.81	1.85
18	.049	1.96	2.00	18	.0403	1.61	1.64
19	.042	1.68	1.71	19	.0359	1.44	1.46
20	.035	1.40	1.43	20	.0320	1.28	1.31
21	.032	1.28	1.31	21	.0285	1.14	1.16
22	.028	1.12	1.14	22	.0253	1.01	1.03
23	.025	1.00	1.02	23	.0226	.904	.922
24	.022	.88	.898	24	.0201	.804	.820
25	.02	.80	.816	25	.0179	.716	.730
26	.018	.72	.734	26	.0159	.636	.649
27	.016	.64	.653	27	.0142	.568	.579
28	.014	.56	.571	28	.0126	.504	.514
29	.013	.52	.530	29	.0113	.452	.461
30	.012	.48	.490	30	.0100	.400	.408
31	.01	.40	.408	31	.0089	.356	.363
32	.009	.36	.367	32	.0080	.320	.326
33	.008	.32	.326	33	.0071	.284	.290
34	.007	.28	.286	34	.0063	.252	.257
35	.005	.20	.204	35	.0056	.224	.228

Specific gravity	Iron 7.7	Steel 7.854
Weight per cubic foot	" 480.	" 489.6
Weight per cubic inch	" .2778	" .2833

As many gages differ, and even the thicknesses of a certain specified gage are not assumed the same by all manufacturers, orders for sheets and wires should always state the weight per square foot or the thickness in thousandths of an inch.

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FAHRENHEIT AND CENTIGRADE TEMPERATURE SCALES

F.	C.	F.	C.	F.	C.	F.	C.	F.	C.
−40	−40.	70	21.1	185	85.	950	510.	2100	1149.
−35	−37.2	75	23.9	190	87.8	1000	537.8	2150	1176.5
−30	−34.4	80	26.7	195	90.6	1050	565.5	2200	1204.
−25	−31.7	85	29.4	200	93.3	1100	593.	2250	1232.
−20	−28.9	90	32.2	205	96.1	1150	621.	2300	1260.
−15	−26.1	95	35.	210	98.9	1200	648.5	2350	1287.5
−10	−23.3	100	37.8	212	100.	1250	676.5	2400	1315.5
− 5	−20.6	105	40.6	215	101.7	1300	704.	2450	1343.
0	−17.8	110	43.3	225	107.2	1350	732.	2500	1371.
+ 5	−15.	115	46.1	250	121.2	1400	760.	2550	1399.
10	−12.2	120	48.9	300	148.9	1450	788.	2600	1426.5
15	− 9.4	125	51.7	350	176.7	1500	816.	2650	1455.
20	− 6.7	130	54.4	400	204.4	1550	844.	2700	1483.
25	− 3.9	135	57.2	450	232.2	1600	872.	2750	1510.
30	− 1.1	140	60.	500	260.	1650	899.	2800	1537.5
32	0	145	62.8	550	287.8	1700	926.	2850	1565.
35	+ 1.7	150	65.6	600	315.6	1750	954.	2900	1593.
40	4.4	155	68.3	650	343.3	1800	982.	2950	1621.
45	7.2	160	71.1	700	371.1	1850	1010.	3000	1648.5
50	10.	165	73.9	750	398.9	1900	1038.	3050	1676.
55	12.8	170	76.7	800	426.7	1950	1065.5	3100	1705.
60	15.6	175	79.4	850	454.4	2000	1093.	3150	1732.
65	18.3	180	82.2	900	482.2	2050	1121.	3200	1760.

To convert Fahrenheit into Centigrade:

Subtract 32 from Fahrenheit and divide remainder by 9 and multiply by 5.

Example: 212 Fahr.

32

180

$180 \div 9 = 20.$ $20 \times 5 = 100.$

Ans. 212 Fahr. = 100 Cent.

Centigrade to Fahrenheit:

Divide by 5, multiply by 9 and add 32.

Example: 260 Cent. $\div 5 = 52.$ $52 \times 9 = 468 + 32 = 500$ Fahr.

Ans. 260 Cent. = 500 Fahr.

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COMPARATIVE ROCKWELL, SCLEROSCOPE AND BRINELL HARDNESS TABLES

(Not High Speed Steel)

Rockwell C Scale, 120 Degree Cone 150 Kilogram Load	Scleroscope Average of Models C and D Scleroscopes	Brinell Numbers	Rockwell C Scale, 120 Degree Cone 150 Kilogram Load	Scleroscope Average of Models C and D Scleroscopes	Brinell Numbers
70	98	745	39	49	321
69	96	725	38	48	311
68	94	712	37	47	302
67	92	682	36	45	293
66	90	668	35	44	285
65	88	654	34	43	277
64	87	627	33	42	269
63	85	614	32	41	262
62	83	602	31	40	258
61	82	590	30	39	255
60	80	578	29	38	248
59	78	555	28	37	241
58	77	545	27	36	235
57	75	534	26	35	229
56	74	514	25	34	223
55	72	504	24	33	217
54	71	495	23	32	212
53	69	478	22	31	207
52	67	461	21	30	201
51	66	452	20	30	197
50	65	444	19	29	192
49	64	429	18	28	187
48	63	415	17	27	185
47	61	401	16	27	183
46	59	388	15	26	179
45	57	375	14	25	174
44	56	363	13	24	170
43	54	352	12	23	167
42	53	346	11	23	165
41	52	341	10	22	163
40	50	331			

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SOME WORTH WHILE BOOKS

Accurate Tool Work by C. L. Goodrich and F. A. Stanley. McGraw-Hill Book Co., Inc., New York, N. Y., Publisher.

American Machinists Gear Book by Charles H. Logue. McGraw-Hill Book Co., Inc., New York, N. Y., Publisher.

American Machinist's Handbook by F. H. Colvin and F. A. Stanley. McGraw-Hill Book Co., Inc., New York, N. Y., Publisher.

Automatic Screw Machines by Douglas T. Hamilton. The Industrial Press, New York, N. Y., Publisher.

Automatic Screw Machines and their Tools by C. L. Goodrich and F. A. Stanley. McGraw-Hill Book Co., Inc., New York, N. Y., Publisher.

Electric Welding by Morgan H. Potter. American Technical Society, Chicago, Ill., Publisher.

Engineering Shop Practice, Vols. I and II by Orlan William Boston. John Wiley & Sons, Inc., New York, N. Y., Publisher.

Forging Practice by Carl G. Johnson. American Technical Society, Chicago, Ill., Publisher.

Foundry Practice by R. H. Palmer. A Textbook for Molders, Students and Apprentices. John Wiley & Sons, Inc., New York, N. Y., Publisher.

Foundry Work by William C. Stimpson and Burton L. Gray. American Technical Society, Chicago, Ill., Publisher.

Gear Cutting Machinery by Ralph E. Flanders. John Wiley & Sons, Inc., New York, N. Y., Publisher.

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